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# THE ORGAN OF CORTI BY PHASE CONTRAST MICROSCOPY.[*]

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## INTRODUCTION.

In studies[1-4] on the histologic effects of intense sound on the inner ear, the degree of injury and its extent within the cochlea has been described in preparations made in the usual manner. The methods of fixation, imbedding in celloidon, sectioning and staining, have served to reveal many alterations in hair and supporting cells of the organ of Corti. They have left much to be desired in the interpretation of the finer changes in the nucleus and cytoplasm of individual cells. In view of the newer and improved methods for physiologic testing it is important to know whether the organ of Corti can recover from mild injuries or to what extent its recovery might take place.

It has been necessary to study by means of the phase contrast microscope freshly isolated pieces of the organ of Corti

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[†] On leave of absence from Tokyo Medical and Dental University for study at Central Institute for the Deaf.

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from control animals before attempting similar observations on animals subjected to intense sound. The present results are concerned with the normal cells and are similar to the studies recently reported by Hilding[5] for the tectorial membrane. A future study will deal with the appearance of the injured cells of the organ of Corti with phase contrast microscopy.

## MATERIALS AND METHODS.

Twelve guinea pigs of about 250 to 400 gm. in body weight were used in this study. Each animal was anesthetized by an intraperitoneal injection of veterinary nembutal and finally given a second dose sufficient to kill. A temporal bone was then removed and the bulla opened to expose the cochlea. Bone adjacent to the cochlea was removed, and the specimen was then immersed in warmed physiological saline solution. Further dissection and preparation of the slides was carried out on a warm table at 37° C. The light source was a Universal microscope lamp, for which the intensity was adjusted and the beam of light focused on the specimen. A binocular dissecting microscope was used with a magnification of about 27 times.

The bone was removed from the apex and into the first turn of the cochlea with a small, sharp hook. Markings of the stria vascularis, Reissner's membrane and the osseous spiral lamina were visible as landmarks. Using small scissors, a cut was made into the modiolus and another through the stria vascularis. The piece was removed to a warm slide and further dissected in saline solution under the same magnification. A small segment of the organ of Corti was removed from the basilar membrane. This usually measured about 1 to 2 mm. in length. It was then transferred to another slide, a drop of saline solution added, and the preparation was then covered with a No. 0 coverglass and ringed with vaseline. The slide was then transferred to the stage of a phase contrast microscope and observed by means of dark, medium objectives. It was at first studied under low power magnification in order to find the areas thin enough for study and photography. Higher magnification was used for study of single cells and most of the photomicrographs. The preparations showed no signs of deterioration before 30 to 40 minutes.

## FINDINGS.

*The Preparation:* As shown in Fig. 1, the preparation under low power magnification (108×) usually consisted of a few millimeters of the organ of Corti removed from the basilar membrane. Other preparations consisted of special mounts of the tectorial membrane, basilar membrane or preparations that included the osseous spiral lamina, organ of Corti, and spiral ligament. For most observations the short segments of hair and supporting cells held in place by the reticular membrane were used. In these the thinner areas about the periphery of the preparation were used for the study of single cells. In Fig. 1 the free margin contains external hair cells and supporting cells, and the tops of pillar cells appear as a fairly homogenous row separating the external from the internal hair cells. Attempts to tease or further isolate single cells for study proved disastrous for the sensory cells. After such treatment the reticular membrane with attached pillar cells and tops of hair and supporting cells usually remained intact. The organ of Corti can readily be lifted from the basilar membrane, but the most resistant and tenacious part of it appears to be the reticular membrane.

Attempts were made to keep the slides in a warm chamber during the time of dissection, preparation and observation. It was found that most preparations were suitable for study for a period of approximately 30 to 40 minutes, and use of the warm chamber during the period of observation did not seem to lengthen this period materially. Beginning disintegration in these fresh preparations was evidenced by: *1.* a swelling of some cells; *2.* a cessation of Brownian movement for most intracellular particles; *3.* a rearrangement of cytoplasmic constituents and the formation of a semisolid phase. This resulted in the formation of networks and a congealed appearance of the cytoplasm with *4.* formation of cytoplasmic

cell. A similar zone of homogenous substance through which the hairs emerge is found at the uppermost portion of the cell.

Fig. 4 offers an opportunity to compare the two types of hair cells (1,000×). The detail of the upper portions of the cells is somewhat obscured by the fibrillar processes of the pillar cells in an irregular arrangement. The nucleus of one external hair cell is located closer to the center of the cell than usual.

The inverted V-shaped pattern of the hairs as they emerge from the external hair cell is shown in Fig. 5 (1,000×). This row of cells as seen from the reticular membrane is the one closest to the external pillar rods; the more peripheral rows of sensory cells are not in focus in this photomicrograph. The hairs of the internal hair cell emerge in a short, straight line and, like the hairs of the external hair cell, each configuration is made up of several rows of hairs.

Fig. 6 is a view of the reticular membrane (2,000×) as seen from above. Its components are octagonal. In the center of the field is an external hair cell with projecting hairs that measure 5 to 8 microns in length. A lateral view (2,000×) of similar cells is shown in Fig. 7. Their length and number for each cell can be well appreciated. The plane of focus in this preparation was on the upper end of the hair cells and as a result they are not fully shown in the photomicrograph. The tectorial membrane was lifted off of the organ of Corti during dissection of the specimen so that its relations to the hairs was not observed. Since the hairs became more distinct in older preparations that had been under observation for some time, it is possible that any binding substances may have dissolved with separation of the individual hairs.

*Supporting Cells:* A Deiter's cell (1,000×) is shown in Fig. 8. It has relatively clear cytoplasm with well defined boundaries. It is a pear-shaped cell from which two fibrillar processes emerge. One process passes to the reticular membrane, another forms a cup-shaped base for an external hair cell. The fibrils originate in the cytoplasm as shown in Fig. 8.

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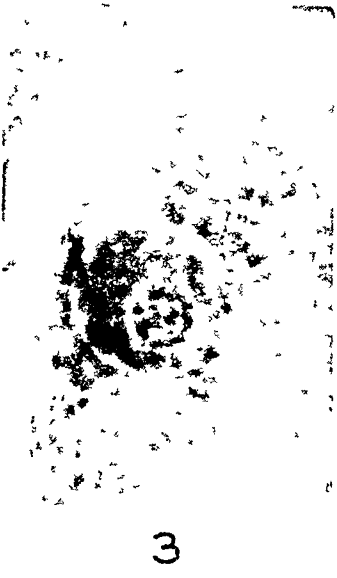

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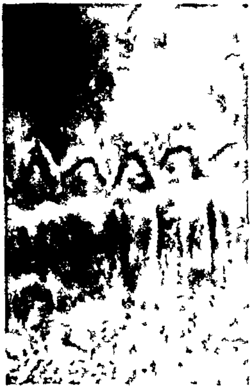

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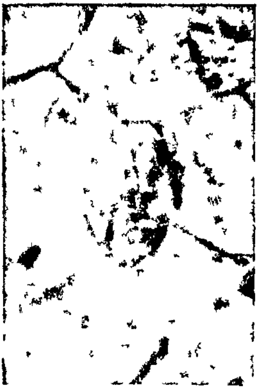

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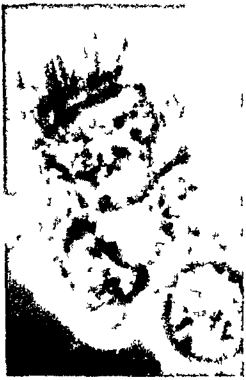

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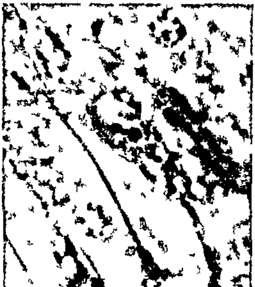

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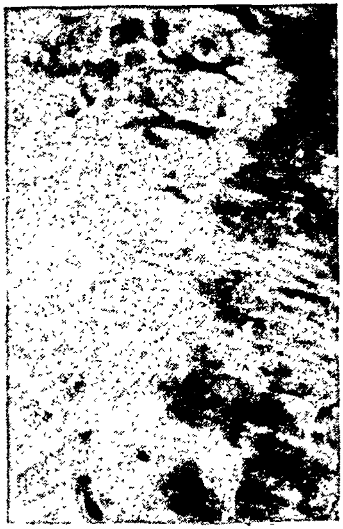

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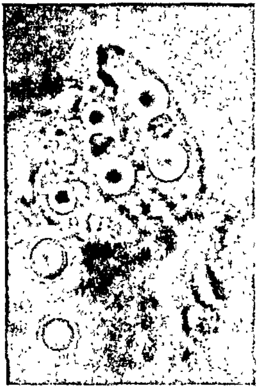

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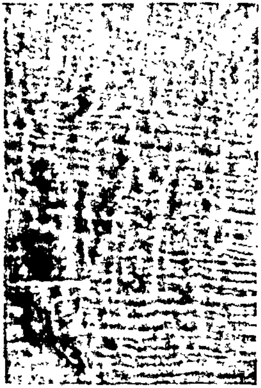

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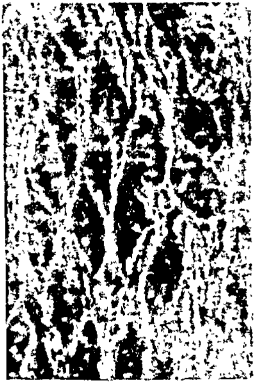

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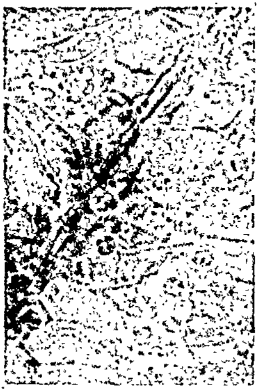

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In this instance a few granules adhere to them at their points of origin. They are usually seen to fan out into three or more strands at their origin, which is located below and to one side of the nucleus. In Fig. 9 (1,000×) are shown the two processes: the one to the left passes upwards to the base of an external hair cell, while the somewhat larger one terminates in the reticular membrane. In Fig. 10 (1,000×) the ends of fibrils can be seen between the hair cells. They are more in evidence to the right in the photomicrograph.

An external pillar cell (1,000×) with its fibrillar supporting process is shown in Fig. 11. It lies between two Deiter's cells. The nucleus is to be seen in the base of the cell that has become detached from the basilar membrane. In contrast to the fibrils in the processes of a Deiter's cell these are more numerous, and each fibril is less distinct in outline; they do not appear to have the same bristle-like rigidity. The fibrils originate in the base of the pillar cells and to one side of the nucleus. As they pass into the rod portion of the cells they become more compact and finally at the top of the tunnel form characteristic terminations that become the apex of the tunnel of Corti.

A photomicrograph of a dark field preparation (108×) of the osseous spiral lamina, basilar membrane and organ of Corti is shown in Fig. 12. The strip containing refractile globules or vacuoles represents the location of the cells of Hensen. They appear similar in preparations made from all turns of the cochlea. Under ordinary illumination they are not apparent in the fresh preparation. Fig. 13 is a higher power (1,000×) of individual Hensen's cells as observed with the phase contrast microscope. The highly refractile bodies are of varying sizes with smaller ones located usually in the tapered base of the cell. The larger ones are usually located about the middle or apex of the cell. Their significance and nature remain obscure. Fat globules have been described as occurring in the cells of Hensen in the apical turn. In fixed and stained preparations they appear as vacuoles and are restricted to the apical areas of the organ of Corti. It seems doubtful that all of these vacuoles seen under the phase contrast microscope are fat. Further studies are under way to determine their nature by histochemical methods.

Hensen's cells are easily removed from the organ of Corti as a continuous piece. They do not seem to be anchored securely in any way to the reticular membrane and, for that reason, one wonders how much, if any, they contribute to support of the organ of Corti.

*Basilar Membrane:* The fibres of the basilar membrane (1,000×) after removal of the organ of Corti are shown in Fig. 14. This represents the appearance of the basilar membrane as viewed from above in its extent through the pectinate and arcuate zones. The fibres have a somewhat wavy appearance under this magnification, and intervening spaces are equal to two or more times the diameter of the individual fibres. They are not very different in appearance from the fibres found in the tectorial membrane. They are to be contrasted with their more fibrous and dense appearance in fixed and stained preparations.

*Mesothelial Cells:* The mesothelial cells (1,000×) on the scala tympanic surface of the basilar membrane are shown in Fig. 15. They are spindle-shaped cells that course in a direction at right angles to the fibres of the basilar membrane. They form a fairly compact layer and each cell resembles a modified endothelial cell.

*Peripheral Nerve Fibres and Nerve Endings:* Nerve fibres (500×) are seen in a part of their course through the tunnel area in Fig. 16, as the external spiral bundle in relation to external hair cells. Fibres to the internal hair cells appear to the left in another focal plane, so detail of their course is unsatisfactory. A number of nerve endings of external hair cells are noticeable. Examination of the base of hair cells shown in Figs. 2, 3 and 4 reveals nerve endings usually for which the connection to the peripheral nerve has been severed. Fig. 17 (2,000×) serves further to illustrate the course of the nerves and their endings on external hair cells. In Fig. 18 (1,000×) two different types of nerve endings are shown in relation to internal hair cells. In one instance (to the right) there is a fine bifurcation of fibres, while to the left of this is a knob-like ending that appears to be single in this instance. Actually these endings are in clusters of two or more. They do not end on the base of the cell but pass somewhat higher and onto the side of the cell and end between cells. Their probable significance will be discussed later.

*Tectorial Membrane:* Usually the tectorial membrane was studied in preparations for which pieces of it had been isolated and mounted. A view of the appearance of such a strip under low power magnification (108×) is shown in Fig. 19. The border to the right was in contact with the limbus, while that to the left was in contact with Hensen's cells. At various levels of focus and with higher power it was possible to visualize certain features, such as the stripe of Hensen, the fibres that comprise the membrane and the network on its surface (see Fig. 20, 1,000×). In this photomicrograph only a small area of the net on its surface and the peripheral border are shown. The next extended over the peripheral half of the membrane, and its strands diminished in size at a point over the hair cells. The substance of which the net-like strands was comprised appeared to be similar to that seen on the border of the membrane overlying Hensen's cells.

## DISCUSSION.

In our opinion the results presented justify the use of the phase contrast microscope in the study of the organ of Corti. It is planned to extend the studies to include other parts of the inner ear and in addition to use other methods, such as electron microscopy. There is no organ in the body for which more observations have been erroneously described as pathologic changes than for the internal ear. Engstrom[6] has recently emphasized the need for a revision of older observations on the labyrinth by the use of newer methods. The need for detailed information regarding finer cell structure is further stressed by the progress now being made in the understanding of the physiologic principles of hearing (Davis and Tasaki[7]).

In the freshly isolated preparations of the organ of Corti there was no tendency for the hair cells to swell or change their shapes. The elongated and narrow external hair cell showed a tendency to bend in the middle third (portion above nucleus), but no distortion of it such as described for certain theories of its stimulation was discernible. The rather firm anchorage of the upper ends of the internal and external hair cells in the reticular membrane and the obviously rigid support of the phalangeal cells and pillar cells tend to produce a unit that is compact and not readily broken up. The anchorage of the organ of Corti to the basilar membrane is not an impressive feature, because it is readily lifted from the latter, as also occurs under experimental conditions, such as acoustic trauma. That the hair cells are the most fragile components of the organ of Corti and more susceptible than other cells to trauma and various agents such as drugs, toxins and so forth, is further borne out by attempts to tease and isolate single hair cells in fresh preparations. The body of the hair cells was usually torn away from the reticular membrane, leaving its cuticular border with the hairs intact. The remainder of the cell thus became lost, probably because it disintegrated rapidly. The preparations that had remained under observation for about one hour began to show progressive stages in deterioration, first in the hair cells and later in the supporting cells. No intracellular fibrillar network was in evidence in freshly mounted preparations. The hair cells appeared quite clear with granules, mitochondria and a ground substance of a nonrefractile type. A semisolid phase in which the ground substance and granules participated became conspicuous with age and deterioration of the preparation. It is possible that fibrils may be present but remain undetected by phase microscopy.

Hensen's cells are regarded as important in their function as supporting cells. Several features are presented in these observations to throw some doubt upon their value as supporting elements for the organ of Corti. In dissection of the organ of Corti they are readily removed in a strip showing that they have no firm anchorage to the reticular membrane or basilar membrane. Perhaps a more plausible explanation of their position is not primarily that of a protective or supporting function but instead a physiological rôle in the maintenance of sensory and other supporting cells of the organ of Corti. Further work is at present under way to determine the nature and fate of the globules and granules revealed in these cells by phase contrast microscopy.

Hilding's[7] excellent description of the tectorial membrane cannot be improved upon by our observations. The net on the surface of the membrane observed by him and also De Vries[8] appears to be comprised of a homogenous substance and blends into the border of a similar material that is described by Hilding as overlying Hensen's cells.

The fibres of the tectorial membrane are similar in appearance to those observed by Katsuki, Mizuhira and Yoshino[9] using contrast microscopy on the cupula of the lateral line organ of fish. They are also similar to the fibres in the basilar membrane of the guinea pig with considerable interfibrillar substance apparent in each structure. In the process of preparing sections of the cochlea this interfibrillar material stains deeply for the basilar membrane and imparts to its appearance that of a dense fibrous structure. For the tectorial membrane the shrinkage and lack of staining of the interfibrillar material reveals a more delicate structure particularly subject to artefacts. The difference between the two structures is probably not in their fibrillar content so much as in their interfibrillar material.

The course of the peripheral nerve fibres in the organ of Corti was observed in many preparations. It was found that the nerve endings of the external hair cells are of one type, while the internal hair cells revealed two types of endings. The unusual ending was a cluster of small knob-like ramifications of the nerve fibres that did not attach itself to the base of the cell but instead was found between internal hair cells. The significance of this type of ending is not clear. Kolmer[10] described two types of endings in the maculae and cristae of human labyrinths but did not observe both types in the organ of Corti. Katsuki and Yoshino[11] described two types in the cells of the lateral line organ of fish in preparations furnished them by H. Yamada. Perhaps these knob-like endings between the internal hair cells are the termination of the efferent fibres described by Fernandez[12] for the bundle of Rasmussen, but the explanation of their presence remains a problem for further study.

## SUMMARY.

The organ of Corti as studied under phase contrast microscopy has revealed information regarding its finer cell structure.

The hair cells are held in place by supporting cells and the reticular membrane. They are the most fragile components of the organ of Corti. They do not change their shapes readily even in preparations that show deterioration. They contain relatively clear ground substance of a nonrefractile type except for granules. Preparations that were about one hour old revealed some deterioration of the cell usually manifested as a semisolid phase of the cytoplasm.

The tectorial and basilar membranes are comprised of fibrils with intervening interfibrillar substance that is probably of different chemical composition in the two structures.

The supporting function of the cells of Hensen is questioned. Further studies are under way to determine the nature of the globules and granules that are seen in the cells with phase contrast microscopy.

Peripheral nerve fibres and their endings are described for the organ of Corti. Two types of endings were observed for the internal hair cells. Their significance is not clear.

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# THE ABSENCE OF RESIDUAL EFFECTS ATTRIBUTABLE TO THE OTOLITH ORGANS FOLLOWING UNILATERAL LABYRINTHECTOMY IN MAN.

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When, under proper circumstances, a healthy person is subjected to a change in direction of resultant force relative to himself, he experiences illusions of a striking nature. Although his position relative to the earth's axis remains the same, he feels as if it were undergoing a change, and objects stationary with respect to himself appear to move and to assume new positions in space. A remarkable feature of these illusions is that they are susceptible to quantitative measurement. Such measurements can be made in terms of the angle through which the apparent movement takes place, the obtained value can be compared not only with another experimental datum but also with the actual angle through which the resultant force moved. It is obvious that these illusions are the result of stimulation of sensory receptors which respond to a change in direction of resultant force and that they represent an attempt at reorientation in accord with the changing lines of force. The sensory organs which respond specifically to this stimulus are the otolith bodies, and it has been stated[15] that persons without otolith organs do not ex-

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Opinions or conclusions contained in this report are those of the authors. They are not to be construed as necessarily reflecting the view or the endorsement of the Navy Department. Reference may be made to this report in the same way as to published articles, noting authors, title, source, date, project number and report number.

Research Report. Project Number NM 001 059.01.33.

Approved by Capt. Ashton Graybiel, M.C., U.S.N., Director of Research.

Released by Capt. James L. Holland, M.C., U.S.N., Commanding Officer.

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perience these reorientation phenomena. Insofar as this is true, these illusions may be used as indicators of the functioning of the otolith organs.

Although these illusions were described many years ago by Purkinje[13] and Mach,[9] it is only recently that they have been the object of intensive study.[3,5,6,20] The apparent movement and displacement of objects in the visual field has been termed the oculogravic illusion.[5] Under favorable conditions there is good correspondence between the rate of apparent movement and the magnitude of apparent displacement in space. It behaves in an orderly manner and, in the case of sophisticated subjects, the test-retest reliability in estimating the magnitude of the displacement is good. The oculogravic illusion is not due to eye-movement; it may be related to the ability to perceive space.[19]

The apparent change in bodily position consists of a feeling of being reoriented in space. The reorientation also applies to the various supporting structures such as chair and floor. Under favorable experimental conditions, the change occurs slowly but is very clearly perceived.

In the experiments now to be reported, the responses to a change in direction of resultant force were compared in two groups of subjects under conditions favorable for the estimation of these two illusory effects. The subjects in the patient group had previously undergone unilateral labyrinthectomy; the subjects in the control group were healthy.

## SUBJECTS AND PROCEDURE.

Ten female subjects participated in the experiment. Five were healthy and had never suffered from any disease or disorder involving the inner ear. In the remaining five, unilateral labyrinthectomy had been performed in the course of treatment for Ménière's syndrome; four right and one left. Three of the subjects had no complaints; one still experienced rare mild attacks of vertigo and one suffered frequent attacks. The clinical findings in these five cases have been described elsewhere in detail.[8]

The experiments were carried out on a human centrifuge of the inertia wheel type.[3] The velocity of rotation of the centrifuge platform was graphically indicated by means of an Esterline Angus Recorder (E-A). A modified airplane gunner's seat was mounted on the centrifuge platform, 15.86 feet away from the center of rotation. The seat could be rotated around a vertical axis and secured in any of four positions in relation to the center of centrifuge, namely, *1.* facing center, *2.* facing forward (90° to the right of center in the direction of rotation of the centrifuge), *3.* facing away from the center (outboard), and *4.* facing backward (90° to the left of center and opposite to the direction of rotation). An interphone allowed two-way communication between subject and operator.

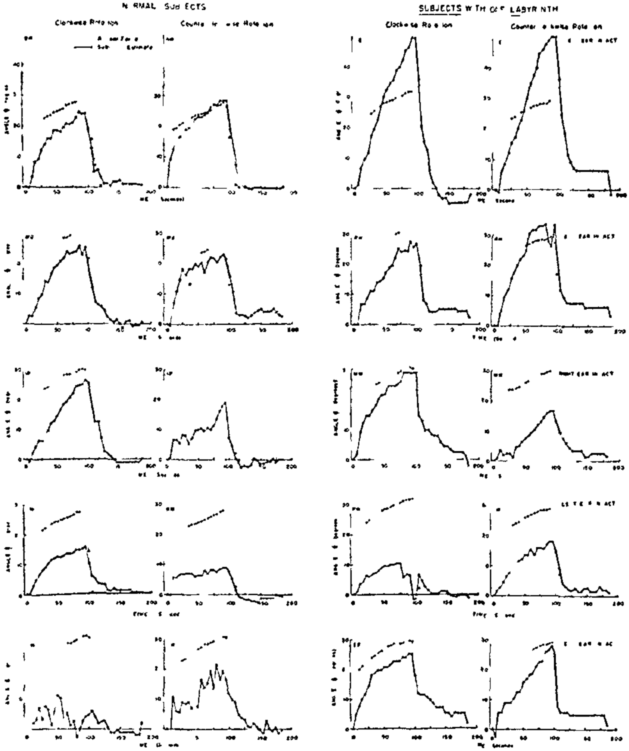
Attached to the seat was a metal frame on which were mounted a target light, biting board, and hand grips. The target light was a modified collimated star.[2] The visual target consisted of two lines of light in the same axis but separated by a short distance. The target could be rotated around an imaginary point dividing the space by which the lines were separated. Clockwise or counter-clockwise rotation was effected by means of a reversible motor under the control of either subject or experimenter. The target was geared to a selsyn transmitter which activated a large needle on a dial calibrated in degrees and situated in the control room. Two pistol-grip hand holds with thumb-operated push-button switches were conveniently placed for the subject's use. Depression of the push-button on the right caused the target to rotate clockwise and on the left, counter-clockwise.

## ESTIMATION OF APPARENT CHANGE IN POSITION OF A VISUAL OBJECT DURING EXPOSURE TO CENTRIPETAL FORCE.

In these experiments the subject's task consisted of maintaining the lines of collimated light in what appeared to be the horizontal position during and for a short time after exposure to centripetal force (maximum angle $\phi \cong$ 30 degrees) for one and one-half minutes. The subject sat erect with head held firmly by means of the biting board and made the necessary adjustments by means of push-button switches incorporated in the hand grip. The phenomenal horizontal was determined both before and after each experimental trial by offsetting the star and requiring the subject, who was shielded from all extraneous light, to return it to what she considered to be the horizontal position. In each instance the average of six offsets, alternately clockwise and counter-clockwise, was determined. Each subject participated in two trials facing forward with the star appearing to rotate clockwise and two trials facing backward with the star appearing to rotate counter-clockwise.

In each experimental trial, the readings on the dial were recorded every five seconds both during the period of acceleration and for a period of one and one-half minutes thereafter. The centripetal force was determined at the same five-second intervals and the angle $\phi$ calculated for comparison with the angle through which the subject rotated the star.

The results are summarized in the form of graphs in Fig. I. Each graph represents the mean values obtained on two trials. The curves have been "normalized" by using as the baseline the subject's phenomenal horizon rather than the true horizontal position. This procedure was equivalent to a translation of the entire curve up or down the ordinate by an amount equal to the subject's error in estimating the horizontal position of the line. A typical "good response" was made by the normal subject BW when observing counter-clockwise rotation. This indicates that she used her original position as the reference criterion for the horizontal and that she estimated the apparent change accurately. A typical "poor response" was made by the normal subject VW when observing clockwise rotation. It is altogether probable that she used her changing apparent position throughout the experimental trial as the criterion reference for the horizontal and set the target line to conform to it. The remaining responses represent greater or lesser degrees of compromise between these two extremes. That so many poor responses were made by the normal subjects is to be explained by their lack of training and experience in this procedure.[11] Almost equally "poor responses" were made by subjects in the control and patient groups. The group differences are small and become insignificant in the light of the great individual variation shown in both groups. The evidence is insufficient that the subjects with one labyrinth responded differently when the application of force was from the right or left side.



APPARENT CHANGE IN DIRECTION OF HORIZONTAL LINE COMPARED WITH CHANGE IN DIRECTION OF THE RESULTANT FORCE (ANGLE Φ) EACH POINT IS THE AVERAGE OF TWO OBSERVATIONS

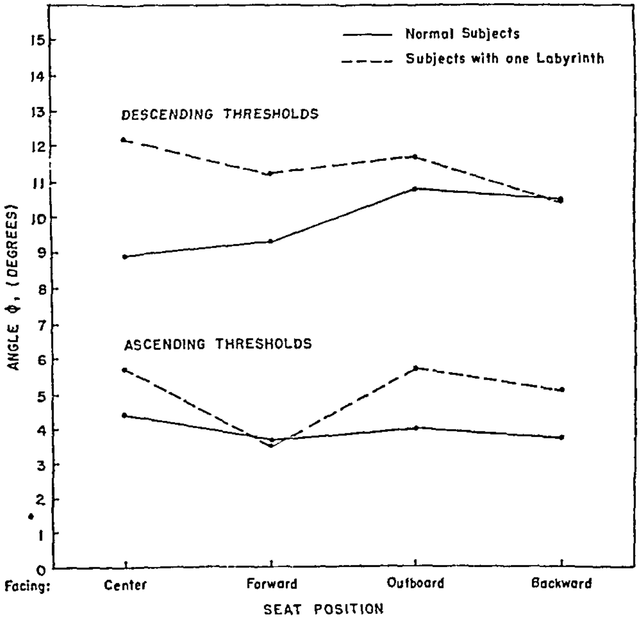
FIGURE I

A comparison of the initial and final target settings shows a better correspondence in the case of the control than in the patient group. Two subjects in the patient group are responsible for nearly all of the difference. The significance of this finding is in doubt because of the small number of subjects tested.

## ESTIMATION OF APPARENT CHANGE IN BODILY POSITION DURING EXPOSURE TO CENTRIPETAL FORCE.

*Threshold Measurements.* In this series of experiments the subject, with her eyes closed and in the dark, was required to signal the moment she first perceived that she was tilted away from the vertical and the moment that she returned. The velocity of rotation of the centrifuge was slowly increased from zero to 7 r.p.m. using a constant throttle setting, after which the engine was disengaged, by means of the clutch, which caused the velocity of rotation to decrease slowly by virtue of the friction in the bearings. The same pattern of acceleration and deceleration was maintained insofar as possible in all experiments. During the first series of experiments the subject sat erect with head held firmly by means of the biting board. The subject was requested to close her eyes and a closely-fitting goggle with opaque lenses provided further protection against external cues. The subject, although not always aware of the onset of rotation, soon felt she was tilting or leaning away from the vertical. The direction of tilt depended upon her position on the centrifuge. The subject on perceiving the tilt signalled the operator, who recorded the velocity at that moment by means of a signal recording on the E-A. During deceleration the subject signalled again when she felt that she was upright and in her original position. Each person was subjected to five experimental trials in all four positions. The initial seat position was randomized insofar as possible, and the five experimental trials were given as a continuous series. Between trials the subject was allowed a two-minute period of relaxation.

The results are summarized in Fig. II. It is apparent that there are no significant differences between the two groups. The similarity in the case of the ascending thresholds, which are more meaningful than the descending thresholds, is striking. The values for the subjects in both groups are slightly lower than in another experiment where highly sophisticated subjects were used.[3,6] In the case of the descending thresholds three of the normal subjects had slightly lower values than the rest. The group differences, however, are small and unimportant. The maximum values recorded were similar for all subjects in all positions.



MEAN ANGLES (Φ) AT WHICH TILT (ASCENDING) AND RETURN TO VERTICAL (DESCENDING) WERE FIRST PERCEIVED IN VARIOUS SEATING POSITIONS. EACH POINT IS THE AVERAGE OF FIVE OBSERVATIONS.

FIGURE II

*Suprathreshold Determinations.* In carrying out these tests the procedure was altered in some respects. Two machinist's combination squares were mounted on the framework of the seat within easy reach of the subject's hands. The "square" consisted of a one-foot grooved metal rule which could be rotated in relation to a protractor head which was scored to read in degrees. In all experimental trials the protractor was secured at the middle of the rule. One square was placed with the rule horizontal and the other with the rule vertical.

In both cases the subject was placed so that she could grasp the ends of the rule and rotate it about its midpoint. Determination of the true horizontal and vertical positions was carried out by means of a level and plumb bob, respectively. Each subject was tested under static conditions and was required, with eyes closed, to adjust the bar within a period of 15 seconds. After a short period of indoctrination, 10 adjustments were made with each bar during the static condition. Following this, the subject was suddenly exposed to a centripetal force (angle $\phi \cong 30$ degrees) for one minute and 30 seconds. She was then required within 15 seconds to adjust the horizontal bar to what she considered to be the horizontal; 10 seconds later, she adjusted the vertical bar to what she considered was the vertical. Each subject made these adjustments during five consecutive experimental trials in each of the four different seat positions. The subject had a brief period of relaxation between trials. Seat position order was randomized.

The results are summarized in Table I. A distinction has been made between the primary and secondary adjustment in each experimental trial. For example, if the direction of centripetal force was such that the subject felt as if she were tilting backward, the primary adjustment would be made with the vertical rod which moved in the same plane as the lines of force, and the secondary adjustment would be made with the horizontal rod which moved in a plane at right angles to it.

If the results are evaluated in terms of the accuracy with which the subjects indicated the change in direction of resulting force, it is obvious that none performed well in all four positions. Some made an accurate adjustment in certain seat positions but not in others. Under-correction was a more frequent response than over-correction, but sometimes no correction was made. One subject (PW) did not make any primary correction for all four seat positions. This subject belonged to the abnormal group and her failure to respond deserves special comment because it could be interpreted as indicating nonfunction of the remaining otolith organ. The

TABLE I.

AVERAGE ERROR OF SUBJECTIVE ESTIMATES OF THE VERTICAL AND HORIZONTAL PARALLEL WITH (PRIMARY ADJUSTMENT) AND PERPENDICULAR TO (SECONDARY ADJUSTMENT) THE PLANE OF RESULTANT FORCE.

| | PRIMARY ADJUSTMENT | | | | SECONDARY ADJUSTMENT | | | |
|---|---|---|---|---|---|---|---|---|
| | Vertical | | Horizontal | | Vertical | | Horizontal | |
| | Facing Center | Facing Outboard | Facing Forward | Facing Backward | Facing Forward | Facing Backward | Facing Center | Facing Outboard |
| *NORMAL* | | | | | | | | |
| B. W. | 22.4 | —21.0 | —26.2 | +25.2 | 4.8 | 6.0 | 1.2 | 2.5 |
| M. G. | 18.7 | —18.1 | —27.9 | 26.7 | 6.3 | —0.1 | —1.7 | —0.6 |
| I. P. | 24.3 | —19.2 | —18.3 | 18.1 | —0.8 | —2.5 | 1.0 | 0.8 |
| K. M. | 22.8 | —24.9 | —30.1 | 29.3 | 7.7 | —0.2 | —0.2 | 0.0 |
| V. W. | 4.7 | —23.7 | —19.2 | 23.9 | 8.0 | 6.2 | —0.5 | 0.2 |
| OPERATED | | | | | | | | |
| L. E. | 21.1 | —25.4 | —26.3 | +31.7 | 6.5 | 1.8 | 2.2 | —1.6 |
| R. H. | 25.8 | —26.9 | —27.7 | 24.9 | —3.1 | —6.8 | 2.6 | —1.2 |
| M. W. | 14.9 | —22.0 | —19.3 | 17.8 | 2.5 | 5.0 | —0.1 | —0.7 |
| P. W. | 29.3 | —30.7 | —27.2 | 35.3 | 0.1 | —6.2 | —0.5 | —1.0 |
| Z. F. | 24.4 | —22.1 | —25.3 | +33.6 | 6.5 | 5.0 | —0.3 | —1.2 |

NOTE: Plus indicates clockwise rotation of test rod; minus indicates counter-clockwise rotation of test rod.

chief argument against this conclusion is the fact that she made two fairly good adjustments when the visual target was used. A further argument is the fact that the consistency of her response was good. The difference in responses between the two groups is insignificant.

## DISCUSSION.

Unilateral labyrinthectomy or its equivalent has been frequently exploited in attempts to unravel the rôle of the nonacoustic portion of the labyrinth. In analyzing the results of such experiments the following first-order variables must be kept in mind: *1.* two organs of special senses are involved, namely, the semicircular canals and the otolith bodies, the separate functions of which can be studied best by selective stimulation or selective suppression, *2.* the immediate effects following operation differ from the residual effects, *3.* the results differ according to the animal species.

Both in animals and in man the immediate results of unilateral labyrinthectomy are severe. There is good evidence that, in certain animals at least, the symptoms arise in part on the injured side and in part from unbalanced effects from the remaining labyrinth.

The residual effects of unilateral extirpation vary greatly depending upon the animal species. In general, the higher the level of phylogenetic development the smaller the residual effects.[10] Thus the frog compensates poorly, the pigeon moderately well, and the dog very well. Compensation involves different mechanisms, but the cerebral cortex plays the dominant rôle.[1]

Of particular interest to us here are the residual effects which might be ascribed to the otolith organs. In animals some of the most characteristic effects following unilateral labyrinthectomy are the forced position of the head, trunk, eyes, and sometimes other portions of the body. These effects decrease gradually following operation and in some animals disappear entirely, but in others a permanent residuum is left. That these effects are of otolithic origin has been shown beyond doubt.[16] They are considered to be due to the uncompensated reflexes arising in the remaining otolithic organ.

It is clearly evident that the results of the experiments on animals cannot be applied directly to man; although in terms of man's position in the phylogenetic series, it would be expected that compensation following unilateral labyrinthectomy would be extremely good. Evidence of residual effects might be sought under static or dynamic conditions. Elsewhere[12] we have reported the results of a static experiment wherein the postural mechanisms were placed under stress. The same subjects were used as in the present experiment, and no differences in response were observed regardless of whether the principal stress fell on the operated or normal side.

In dynamic tests the otolith organs may be stimulated by tilting the subject's head in relation to the lines of gravity or changing the direction of the lines of force with the subject's head remaining fixed. Gollas[4] studied seven patients by measuring the counter-rotation of the eyes. When the patients were inclined toward the side of the nonfunctioning labyrinth, the counter-rotation of the eyes was normal, and when they were inclined toward the normal labyrinth, the counter-rotation of the eyes was diminished. From this it was concluded that although the remaining labyrinth acts upon both eyes, the effect is unequal. Spiegel and Sommer,[14] utilizing Grahe's table, also carried out experiments on subjects with a single functioning labyrinth. Following a tilt toward the operated or normal side, subjects were required to estimate the vertical position. The results indicated a displacement of the phenomenal vertical toward the injured side. Thetford and Guedry[17,18] were unable to confirm these findings in our subjects. Utilizing a tilt room, they found no displacement of the phenomenal vertical toward the injured side and no significant differences in response between normal subjects and those with a single labyrinth.

Dynamic experiments similar to those described in this report have been carried out using deafmutes as subjects.[1] When exposed to a change in direction of the lines of force, many of them did not give any indication that they reorientated themselves in accord with this change. It was concluded that failure to do so was attributable to the absence or nonfunctioning of the otolith organs. If this conclusion is accepted, it furnishes a strong argument that such a procedure is adequate to test the function of the otolith organs. Our negative results, therefore, are significant and allow the conclusion that under the conditions encountered in our experiments, persons with a single otolithic organ respond the same as normal persons with a synergic pair. Stated differently, the evidence suggests that compensation following the loss of the otolith organ on one side is, for practical purposes, complete.

## SUMMARY.

Healthy subjects and subjects who had previously undergone unilateral labyrinthectomy for Ménière's disease were exposed to centripetal force on a human centrifuge. The change in direction of the lines of force relative to the subject produced striking illusions wherein objects in the visual field appeared to change their position in space, and the bodily position seemed to have changed. A comparison of the responses made by the subjects in the two groups revealed insignificant differences. It was concluded that under the experimental conditions defined, subjects with a single labyrinth respond normally when gravity receptors are stimulated. If it is assumed that the otolith bodies are specifically involved, it may be further concluded that the residual effects attributable to the unilateral loss of these sensory organs are insignificant or nil.

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# THE USE OF DIHYDROGENATED ERGOT ALKALOIDS IN OTOLARYNGOLOGY: A PRELIMINARY REPORT.*

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A consideration of the pathologic physiology involved in certain otolaryngologic disorders would indicate that blockage of the sympathetic nerve supply to the area involved might be of therapeutic value. Our purpose is to present a preliminary report on the usefulness of such a sympathetic inhibitor — a combination of dihydrogenated ergot alkaloids known as Hydergine(R). The number of cases of each type we have to report (see Table I) is admittedly small, but as far as we know, this is the first report to appear in the English literature on the use of this drug in otolaryngology. We hope this factual report will stimulate a more widespread evaluation of this medication and of the therapeutic approach used.

TABLE I — TYPES OF CASES

| | |
|---|---|
| Vertigo | 37 |
| Hypertensive epistaxis | 11 |
| Dryness of the mouth | 13 |
| Glossodynia | 11 |
| Postnasal discharge | 17 |
| Atrophic rhinitis and nasopharyngitis | 12 |
| Miscellaneous | 15 |
| Total | 116 |

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*From the Department of Otolaryngology, the Tulane University of Louisiana School of Medicine, and the Eye, Ear, Nose and Throat Hospital, New Orleans, La.

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## PHARMACOLOGY.

Ergotoxine, one of the alkaloids of ergot, has been shown to be composed of ergocornine, ergocristine and ergokryptine. In the natural state, their vasoconstrictor action overshadows their inhibitory effect on the sympathetic nervous system. Hydrogenation, however, causes the sympathetic blocking action to become predominant, the vasospastic action being virtually eliminated.[1] In addition, probably because of the relatively purer state of these compounds, toxic reactions from their use are almost nil.

In this clinical study, the preparation used was an equiproportional mixture of the three hydrogenated alkaloids of ergotoxine.* For the most part, the medication used was in the form of sublingual tablets, although, in some cases, parenteral administration and sublingual drops were resorted to. Each sublingual tablet contained 0.167 mgm. of each of the dihydrogenated alkaloids; each 1 cc. ampoule of the parenteral form and sublingual drops contained a like amount.

Among the pertinent pharmacodynamic actions of the ergotoxine group which have been reported by various investigators are:

*1.* Depression of the central vasomotor centers with resultant vasodilatation and, in some cases, a fall in blood pressure.[2]

*2.* Peripheral vasodilatation.[3]

*3.* Central inhibition of pressor-receptor reflexes which bring about compensatory vasoconstriction and arterial blood pressure rise.[4]

*4.* Centrally induced bradycardia; this is rather unusual among sympathetic blocking agents.[5]

*5.* Central sedative action; also augmentation of barbiturate action.[6]

*6.* An adrenosympathicolytic effect.[7]

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*Provided for this study by the Sandoz Chemical Co. Hereinafter referred to as Hydergine for the sake of brevity.

*Toxic Manifestations:* In the course of this study, only four persons reported untoward manifestations which were attributed to the drug. Three of these suffered with nausea which was not severe enough to warrant withdrawal of the medication. The fourth experienced weakness, slowing of the heart rate, nausea and headache; in this case the drug was discontinued.

### VERTIGO.

Hilger and Goltz[8] and Williams[9] have very brilliantly described what might be called "the vasomotor syndrome of the inner ear."

Hydergine was administered to 37 patients whose vertigo was ascribed to a vasomotor imbalance of the inner ear. Following a thorough history, a complete ear, nose, and throat examination, caloric tests, and, in some instances, audiograms were done. In 33 instances there was marked to complete remission of symptoms; four patients reported little or no improvement. Williams urges the use of a combination of therapeutic agents in such cases; in the vast majority of our cases, no medication other than Hydergine was used.

The following are typical case histories:

Mrs O H, age 70 This patient gave a history of having frequent attacks of postural vertigo for six weeks prior to her first visit No history of hearing loss or tinnitus Physical examination of the ears, nose and throat was negative The Eustachian tubes were freely patent bilaterally Caloric tests revealed hyperactivity of the left labyrinth The patient stated that the vertigo caused by the caloric test, while similar to that spontaneously experienced, was not quite so severe She was given one sublingual tablet four times a day At the end of one week, she reported 90 per cent improvement During the second week of therapy, she experienced only two mild attacks, since then, she has been asymptomatic

Mrs L K, age 29 This patient experienced a sudden onset of recurrent attacks of postural vertigo and nystagmus At about the time of onset of this condition, there was angioneurotic edema of the upper lip on the left An audiogram revealed mild depression of the threshold for low tones by air conduction Hydergine sublingual tablets were started, and within 48 hours the nystagmus had ceased and there was a marked reduction in the amount of vertigo At the end of 96 hours the patient was asymptomatic Following a week of therapy, the medication was stopped by the patient and she promptly became vertiginous again within 24 hours The medication was resumed and control was again achieved

F. G, age 53 For two months prior to the first visit this steel construction worker had been experiencing repeated episodes of vertigo of the mobilization, the more rapidly and frequently does the hearing return to the preoperative level

We still consider the stapes mobilization operation an acceptable surgical procedure worth developing further, and we regularly perform it first when operating on patients with clinical otosclerosis If no result is obtained, we then resort to fenestration

Haartmanink 4

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# SEVENTH INTERNATIONAL CONGRESS OF BRONCHOESOPHAGOLOGY

The Seventh International Congress of Bronchoesophagology will be held at Kyoto (Japan) University, September 12-14, 1958, under the direction of Prof Mituharu Goto, M D , Otorhinolaryngological Clinic, Kyoto University Hospital, Kyoto, Japan

A registration fee of $25 00 U S A will be charged all physicians and a fee of $10 00 for wives or non-medical guests Registered members are admitted free to banquet, receptions and sightseeing tours

Closing date for scientific papers will be April 30, 1958 A summary of paper, not to exceed 800 words, should be sent to the Director not later than that date

# GENERAL ANESTHESIA IN BRONCHOSCOPY, ESOPHAGOSCOPY AND LARYNGEAL SURGERY EMPLOYING THE EMERSON "RAINCOAT" RESPIRATOR*

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HARRY ASHMAN, M D ,
ALVIN WELFELD, M D ,
JEROME SNYDER, M D ,
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Because of the many difficulties associated with general anesthesia when employed for peroral endoscopy, local analgesia, although not necessarily the patient's choice, has remained the endoscopist's choice in these procedures

There have been numerous general anesthesia techniques described,[1 2 3 4] which have sought to resolve the major problem of maintaining adequate respiratory exchange in a deeply anesthetized or curarized patient, with the surgeon working in the zone of anesthesia administration All of these methods have the basic physiologic fault of inadequate ventilation with retention of carbon dioxide

This problem has now been resolved by the use of a modified polio chest respirator, which efficiently maintains respiratory exchange in a lightly anesthetized but totally curarized patient

The respirator consists of a plastic or rubber raincoat, which slips over the patient's head and trunk It fits snugly around the neck and wrists A wire cage is placed under the raincoat so that there is at least a six-inch space between the

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raincoat and the patient's chest (see Fig 1) The raincoat is then tucked in snugly between the thighs A two-inch opening rimmed with rubber is located in the chest region of the raincoat, to which can be attached the suction hose from a specially designed vacuum pump This has been fitted with a valve that permits it not only to create, very rapidly, an intense vacuum by sucking air out of the raincoat enclosed area, but also alternately permits air to reenter the

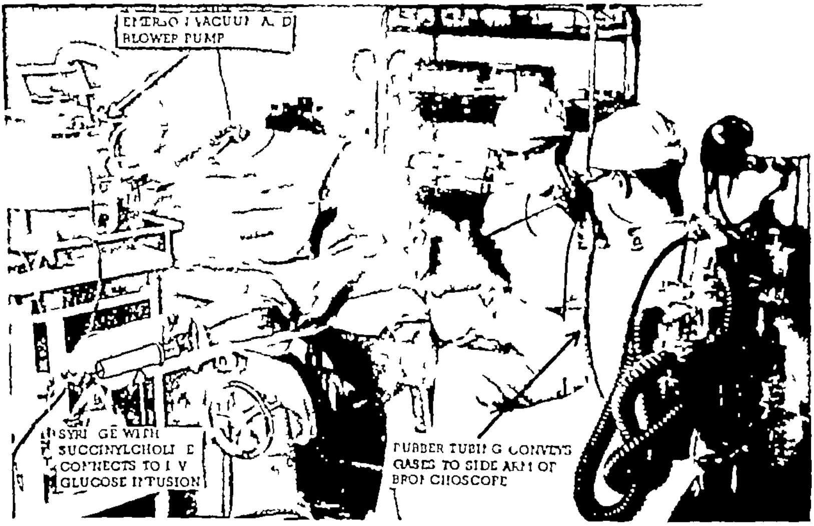

EMERSON VACUUM AND BLOWER PUMP
SYRINGE WITH SUCCINYLCHOLINE CONNECTS TO I V GLUCOSE INFUSION
RUBBER TUBING CONVEYS GASES TO SIDE ARM OF BRONCHOSCOPE

Fig 1 Bronchoscopy Patient is maintained in state of total paralysis by intermittent I V injections of succinylcholine Light anesthesia is maintained by insufflating a mixture of $N_2O+O_2+$Cyclo through side arm of bronchoscope Patient's head held by assistant Respirator will maintain efficient respiratory exchange indefinitely Leakage around patient's neck wrist and thighs is minimal and of little significance since vacuum causes raincoat to adhere to skin

area, thus establishing a ventilation pattern which maintains not only tidal volume, but may even be used to hyperventilate the patient The suction causes expansion of the chest wall which produces inhalation, while the alternate re-entrance of air back into the cage causes the chest to fall, producing exhalation A patient lightly anestheteized and totally paralyzed with succinylcholine can thus be ventilated with complete efficiency

There is no limitation to the length of time the operator can work, and he can proceed in a leisurely and thorough manner, not being hurried by discomfort or fear for the condition of the patient A laryngoscope with a Lewy laryngoscope holder (see Fig 2) can be rested on the patient's chest wall, thus allowing operations on the larynx while the operator has two hands free for maneuvers With succinylcholine the larynx is at rest in abduction, leaving the free margins of the vocal cords along with the subglottic region easily visible

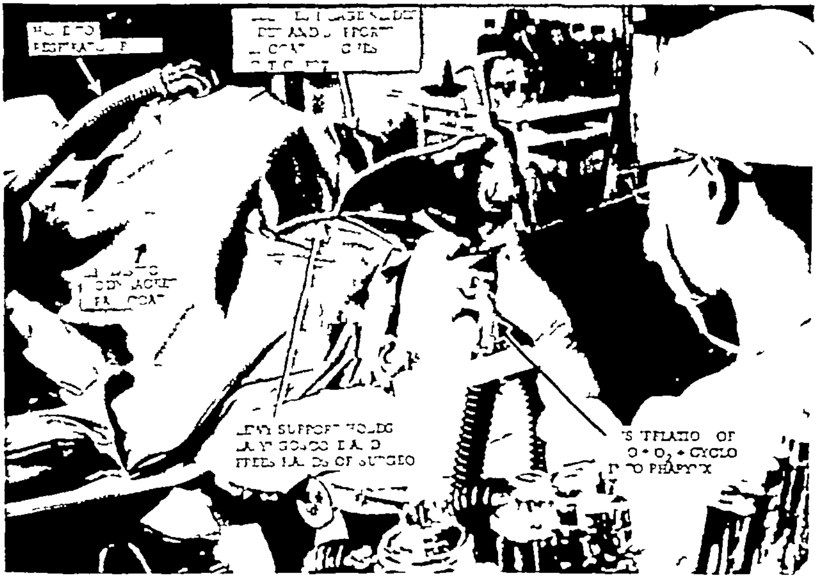
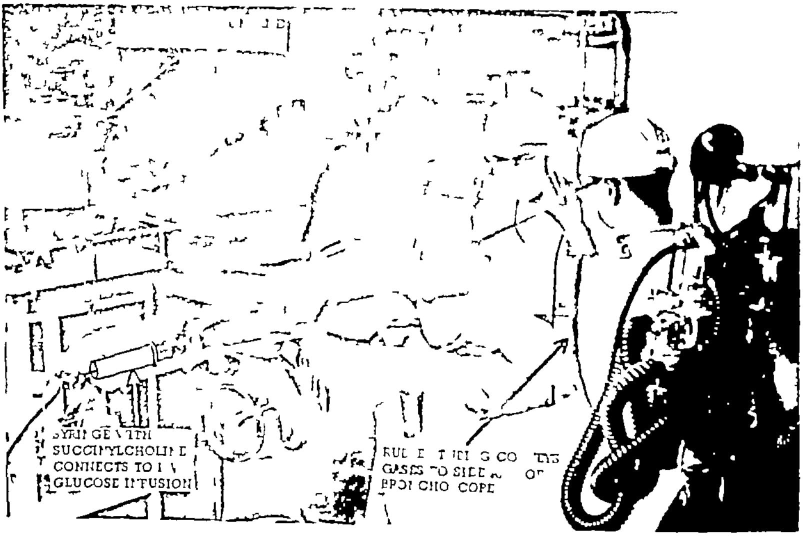


Fig 2 Laryngeal Surgery Light anesthesia is maintained by insufflating N O+$O_2$+Cyclo through a naso-pharyngeal tube the tip of which lies at the uvula Paralysis is maintained by intermittent injections of succinylcholine A Lewy support holds laryngoscope which frees surgeon's hands Respirator breathes for patient by creating first a negative then a release of pressure around chest wall

Esophagoscopies are facilitated and safer on a completely relaxed patient with better visibility and less chance of traumatic perforation

Bayuk[5] was the first to describe the use of a polio chest shell for maintaining respiratory exchange in curarized patients subjected to peroral endoscopy, however, the chest raincoat and the patient's chest (see Fig 1) The raincoat is then tucked in snugly between the thighs A two-inch opening rimmed with rubber is located in the chest region of the raincoat, to which can be attached the suction hose from a specially designed vacuum pump This has been fitted with a valve that permits it not only to create, very rapidly, an intense vacuum by sucking air out of the raincoat enclosed area but also alternately permits air to reenter the area, thus establishing a ventilation pattern which maintains not only tidal volume, but may even be used to hyperventilate the patient The suction causes expansion of the chest wall which produces inhalation, while the alternate re-entrance of air back into the cage causes the chest to fall, producing exhalation A patient lightly anesthetized and totally paralyzed with succinylcholine can thus be ventilated with complete efficiency


SYRINGE WITH SUCCINYLCHOLINE CONNECTS TO I V GLUCOSE INFUSION
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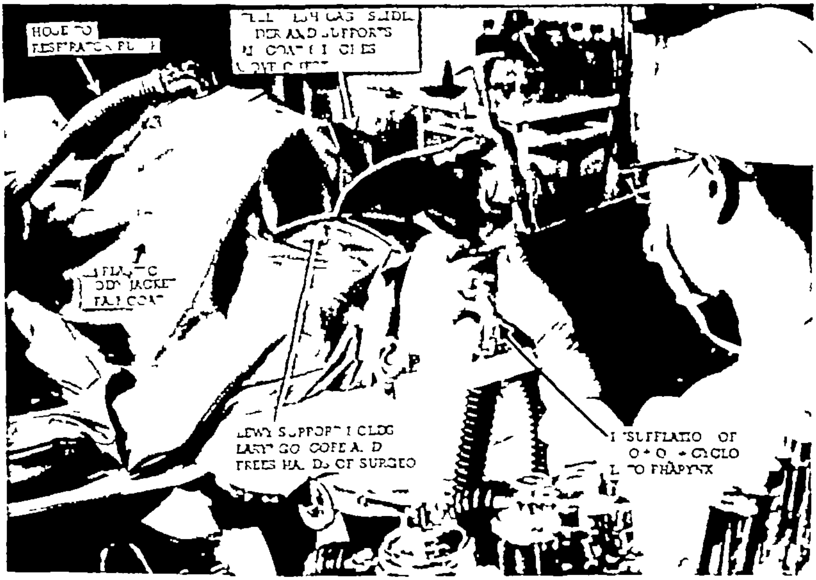

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## BRONCHOSCOPY

The patient first dons the plastic raincoat, or poncho, and after placing the steel mesh cage over the chest (under the raincoat) the neck and arm strings are tightened to prevent leakage of air in or out An intravenous glucose infusion is first established so that a patent vein will always be available to maintain succinylcholine paralysis

The patient is then lightly anesthetized by any favorite method, then rendered apneic by succinylcholine and the respirator turned on The bronchoscope is then passed into the trachea while oxygen, with anesthetic gases are continuously administered through the side-arm of the instrument It is advisable to pass the bronchoscope quickly, since the extreme relaxation may produce obstruction of the glottis because of a relaxed epiglottis It is sometimes more efficient to pass the bronchoscope through a laryngoscope for this reason Adequate exchange prevails throughout the state of paralysis If the patient reflexly moves additional succinylcholine is injected

## LARYNGEAL SURGERY AND ESOPHAGOSCOPY

In laryngeal surgery anesthetic gases must be administered by insufflation to maintain unconsciousness, and this is done by means of a nasopharyngeal tube, which does not enter the trachea

For laryngoscopy and laryngeal surgery the vocal cords are continuously under direct observation since they are the surgical target, and patency of the airway is thus assured by direct vision

In esophagoscopy, on the other hand, airway patency is not assured, and partial obstruction may exist even though the respirator is operating efficiently In order to assure airway patency during esophagoscopy a stethoscope should be attached to the patient's neck at the larynx with adhesive, so that ventilation can be continuously monitored This is essential, since succinylcholine paralysis produces complete relaxation of the tongue, which often falls posteriorly to obstruct the airway even though the esophagoscope is in place In order to prevent tracheal collapse from the instrument, an endotracheal tube may be inserted via the nose prior to introducing the esophagoscope, and the anesthetic gases delivered through this naso-endotracheal tube

## ANESTHESIA TECHNIQUE

Patients may be induced with methitural (Neraval), hexobarbital (Evipal), or thiopental (Pentothal) We prefer methitural, since there is less postoperative inebriation In addition, the return to consciousness occurs much more rapidly than with the other barbiturates

The induction dose of the three drugs in the average adult is

Methitural—10 cc of a 4 per cent solution

Hexobarbital—10 cc of a 4 per cent solution

Thiopental—8 cc of a 4 per cent solution

As soon as the methitural is injected a mask is placed on the patient's face, and a mixture of nitrous oxide, cyclopropane and oxygen is administered in a semi-closed system as follows

Cyclopropane—700 cc per minute (11 7 per cent)

Nitrous oxide—2000 cc per minute (29 8 per cent)

Oxygen—4000 cc per minute (58 5 per cent)

This mixture of gases will produce light, plane I anesthesia within three to five minutes, and no matter how long it is administered a level of anesthesia deeper than plane I will be impossible to achieve We have used this exact mixture in over 30,000 patients during the past nine years for every type of surgery Details of its administration have been described fully elsewhere[6-8]

When plane I is established, 20 mg of succinylcholine is injected through the intravenous infusion needle At the occurrence of respiratory arrest the Emerson respirator is turned on, and the breathing bag on the anesthesia machine is observed so that inflation and deflation occurs with each respiratory cycle While still under succinylcholine paralysis the mask is removed from the face, and the bronchoscopist inserts the bronchoscope quickly To the side-arm tube of the bronchoscope is attached a piece of wide bore rubber tubing through which is insufflated exactly the same mixture of nitrous oxide, oxygen and cyclopropane If the patient should reflexly move, or if added relaxation is requested, an additional cc of succinylcholine (20 mg ) is injected intermittently whenever necessary When the operation is over, pure oxygen is insufflated through the bronchoscope for about two minutes prior to removing it When the patient's own respiratory efforts resume the Emerson respirator is turned off

For laryngeal surgery the same mixture of gases is insufflated through a nasopharyngeal tube which is inserted through the nose, only to the uvula In esophagoscopy a stethoscope should be taped to the neck in the region of the larynx so that respiratory exchange can be monitored, in the event an endotracheal tube is not used

## SUMMARY

A new method of assuring adequate ventilatory exchange during bronchoscopy, esophagoscopy and laryngeal surgery under light general anesthesia, with full curare paralysis, has been described An Emerson body jacket raincoat over a steel mesh cage is employed in conjunction with a special vacuum pump respirator to provide intermittently expansion and compression of the chest wall, which thereby assures efficient ventilation

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and their treatment, as well as the technique of the various procedures is considered

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# PROGRAM OF THE SEVENTH INTERNATIONAL CONGRESS OF BRONCHOESOPHAGOLOGY

Meeting Place—Kyoto University, Kyoto, Japan

Friday, September 12th, 1958

8 00 P M -10 00 P M —Reception (Party) Shimomura House in Kyoto

Saturday, September 13th

8 00 A M —Inaugural Session (in Kyoto University Hall)

9 00 A M -12 00 M —First Scientific Session

12 00 M -2 00 P M —Luncheon (Reception The Place not decided)

2 00 P M -6 00 P M —Sightseeing in Kyoto

8 00 P M —Banquet, Miyako Hotel

Sunday, September 14th

8 00 A M -11 30 A M —Second Scientific Session

11 30 A M -12 00 M —Closing Ceremony

12 00 M —Departure for sightseeing in Nara

1 00 P M —Luncheon, Nara Hotel

2 00 P M -6 00 P M —Sightseeing in Nara

7 00 P M —Return to Kyoto

# INTRA-AURAL MUSCLE CONTRACTION IN MAN, EXAMINED BY MEASURING ACOUSTIC IMPEDANCE OF THE EAR*

AAGE R. MØLLER,

Stockholm, Sweden

## INTRODUCTION

Inasmuch as the intra-aural muscles appear to be of some importance to the function of the ear, it is desirable to understand their behavior in greater detail. The contraction takes place bilaterally when one ear is stimulated by a strong tone, with a minute, but clearly measurable, delay in relation to the stimulating tone. The latent period before the reaction of the muscles is significant, in that the muscles must be regarded as inactive during this latency. The majority of the knowledge we have concerning the function of the intra-aural muscles has been obtained from animal experiments, as it has been difficult to study the action of the muscles in man. Usually the stimulus has been applied to one ear, while the other ear has been used for measuring the muscle contraction.

A report will be made here of an investigation of the contraction of the intra-aural muscles in man, carried out by using measurement of the acoustic impedance in the external auditory canal. Both the latent period of a contraction, shown as a change in impedance, and the degree of the impedance change as a function of the intensity of the stimulus will be studied.

## EARLIER INVESTIGATIONS

The function of the intra-aural muscles has been studied by many writers. The majority reach the conclusion that a muscle contraction causes a decrease in transmission, espe-

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cially with lower frequencies Hallpike and Smith observed that a muscle contraction effects a decrease of the cochlear potential in cats Wiggers (1937) studied guinea pigs, in which spontaneous contractions of the intra-aural muscles occur under light urethan anesthesia, and found a drop in the cochlear potential at lower frequencies when the muscles contracted At 400 c/s a decrease of 20 db was observed, at 1100 c/s there was no change, and at 1500 c/s an increase in the transmission took place when the intra-aural muscles contracted Above 2000 c/s there was no change Galombos (1942) investigated bats and found activity of the intra-aural muscles at frequencies up to 55 kc/s Death or anesthesia increased the cochlear potential for a strong signal, and this was taken by the writer to indicate that the intra-aural muscles affect a reduction in the transmission, and that the cochlear potential, therefore, increased when the muscles relaxed because of death or anesthesia Wever and Vernon (1954) studied the cat, measuring the cochlear potential and finding that the reduction in transmission was very slight above 500 c/s but increased below that frequency The writers state that the stimulating tone was only about 2 db above the contraction threshold They observed, moreover, that the drop in transmission increased when the intensity of the stimulus was increased When the stimulus was 20 db above the contraction threshold, a reduction of about 20 db was observed at 300 c/s The stimulus frequency was 1000 c/s With only tensor tympani active (with the stapedius tendon severed) there was practically no reduction in the transmission

Metz observed that a contraction of the intra-aural muscles effects a change in the impedance of the ear He found that the transmission reduction can be measured as a change in impedance in the external auditory canal, principally as a change in absorption The angle of the reflection co-efficient remained almost constant during a muscle contraction Using the same method, Jepsen studied the threshold value for a muscle contraction in relation to the auditory threshold In order to determine which muscle caused the change in absorption, he examined seven patients with facial nerve paralysis, but was unable to demonstrate any change in impedance accompanying stimulation of the contralateral ear On the other hand he observed a normal impedance change in two patients with trigeminal paralysis This he accepted as proof that the cause of a change in sound absorption is a contraction of the stapedius muscle and not of the tensor tympani Jepsen further demonstrated that the threshold for muscle contraction observed with help of impedance measurement agrees closely with that obtained visually by observance of the stapedius tendon through a perforation in the tympanic membrane

The various earlier studies of the latent period for a contraction of the intra-aural muscles were carried out, using a variety of methods which are reflected in the results Kobrak (1930) studied rabbits and used flute tones as stimuli As indicators for muscle contraction he employed myographs attached to the tendons of the muscles He obtained a latency of between about 30 and 150 msec for the contraction of the stapedius, and between about 75 and 150 msec for the tensor tympanic Lorente de No (1935) studied the contraction of the tensor tympanic in rabbits under ether anesthesia He used, as did Kobrak, myographs as indicators, but employed a better-defined stimulus in the form of a tone produced by a loudspeaker As a result he obtained a latency of approximately 20 msec when the stimulus was about 15 db above the contraction threshold When the stimulus was more than 35 db above the contraction threshold, he observed a latent period of from 12 to 13 msec

Tsukamoto (1934) examined rabbits under light urethan anesthesia He used change in pressure in the labyrinthine fluid as an indicator of the contraction of the intra-aural muscles, recorded with the help of a capillary tube He used a flute tone as stimulus With this method he found a mean latency of 370 msec

Perlman and Case (1939) registered action potentials from the tendon of the stapedius muscle in man in a contraction of the stapedius caused by stimulation with a tone at 1000 c/s applied to the contralateral ear The intensity of this tone is described by the writers as "loud" Their results obtained on a number of experimental subjects gave a mean latency of

10 5 msec Bornschein and Krejci studied rabbits, registering action potentials from the tensor tympanic muscle The experimental animals were under local anesthesia A click was used as stimulus The latent period was found to be 12 to 13 msec

Lorente de No and Bornschein and Krejci observed that the contraction of the intra-aural muscles in rabbits exhibited rhythmic changes (waves) in muscular tension and action potential, respectively The frequency of these changes was

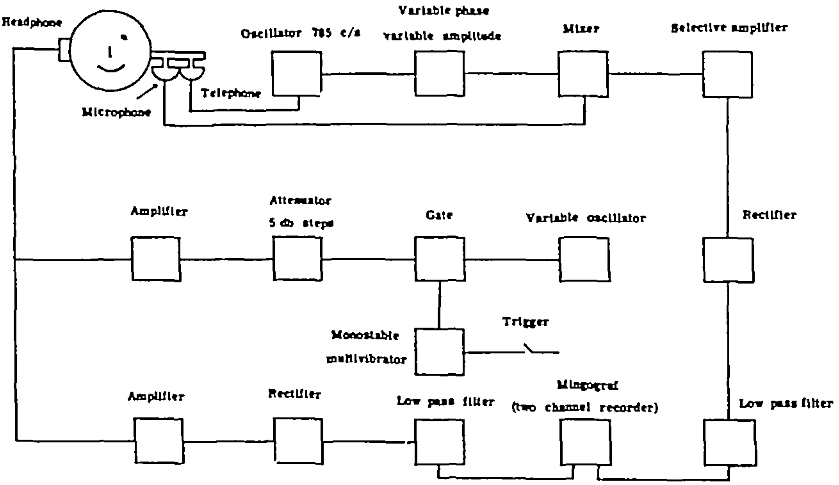

Fig 1 Block-scheme of complete equipment

15 to 20 c/s according to Lorente de No, and 15 c/s according to Bornschein and Krejci

Metz (1951) investigated the latency of contraction in the intra-aural muscles in man by recording changes in the acoustic impedance of the ear, measured by means of a so-called Schuster bridge He observed that the latent period was dependent upon the intensity of the stimulus A stimulus 80 db above the threshold of hearing gave a latency of 150 msec, 90 db above gave 50 msec, and 100 db above gave

In order to find a closer relation between the latent period
a latency of 40 msec

and the intensity of the stimulus, as well as the variation in the results from person to person, the present investigation, using impedance measurement, was started The reproducibility of the measurements was also investigated

## INSTRUMENTATION

The equipment used was designed to deliver a stimulating tone of known frequency and intensity and to indicate a muscle contraction A muscle contraction was shown by recording changes in the acoustic impedance of the ear The acoustic impedance was measured at a frequency of 785 c/s

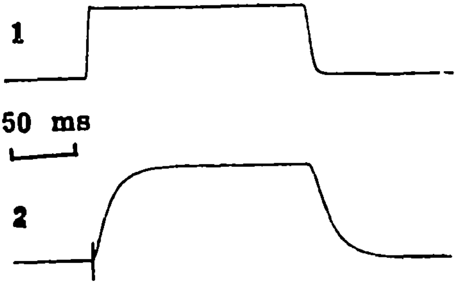

Fig 2 a Pulse response of the selective amplifier The upper curve (1) represents a tone-pulse (785c/s) applied to the input of the amplifier and the lower curve (2) represents the output from the amplifier Both signals are rectified and low-pass filtered with 100 c/s cut-off frequency

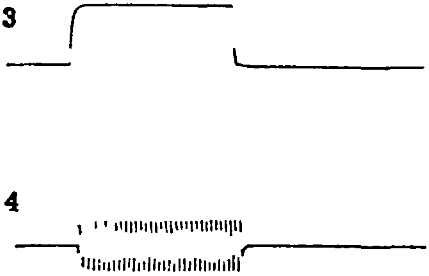

Fig 2-b The wave form of the stimulus pulse (3) is stimulus 2500 c/s rectified and low-pass filtered with 700 c/s cutoff frequency (4) is stimulus 250 c/s direct recorded

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[a] Fig 1 shows a block scheme of the equipment used Stimuli are produced by means of an earphone of Permoflux type PDR 10 The signal to the earphone is delivered by an oscillator with variable frequency which feeds the earphone via a gate circuit and an attenuator A signal from a monostable multivibrator opens the gate in a manner that prevents the occurrence of a click The curve form of the tone pulse produced by the gate circuit is shown in Fig 2

The impedance change is indicated by means of a special measuring device consisting of a telephone and a microphone both connected to a tube 4 mm in diameter which is inserted into the auricular canal A signal at 785 c/s is fed to the telephone The output voltage of the microphone represents the acoustic impedance in the ear measured in the external auditory canal The output voltage is compared with a variable voltage having the same frequency When this voltage has the same amplitude as the voltage arriving from the microphone and opposite phase the reading is 0 When the acoustic impedance changes the voltage from the microphone also changes and the resulting reading

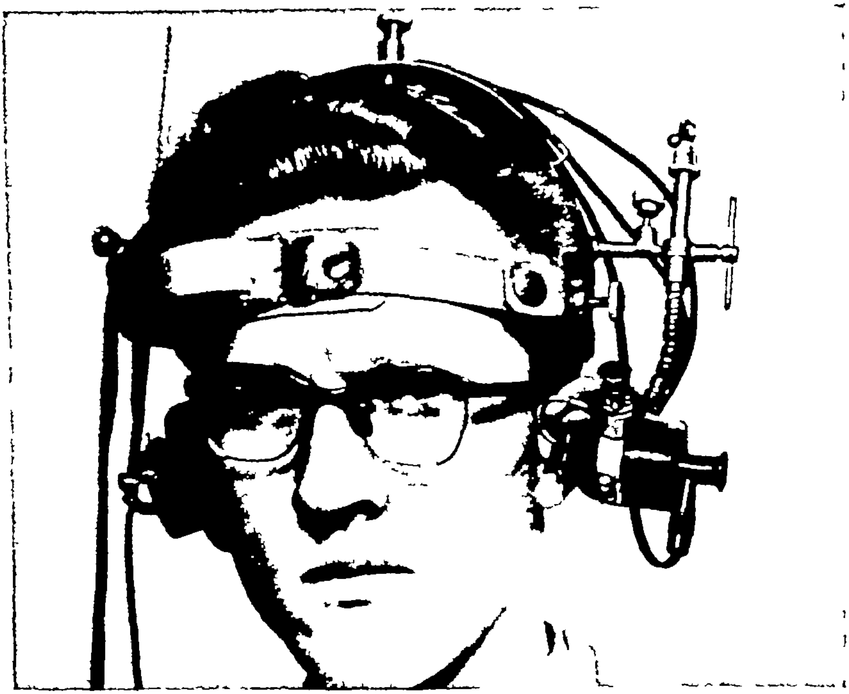

Fig 3 The arrangement of headphone and impedance measuring unit in position on experimental subject

will no longer be 0 This voltage corresponds to a change in impedance which is the result of a muscle contraction The signal is amplified rectified and filtered before it is fed into one channel of the recorder In addition the signal to the earphone is amplified in the same manner as the signal that indicates a muscle contraction and is thereafter fed to the other channel of the recorder The latency is then evident as the time difference between these two signals The prerequisite for this is that the apparatus be corrected for possible variations in the location of the loops in the recorder and for delay in the selective amplifier amplifying the signal indicating a muscle contraction The delay in the two low pass filters used to filter the rectified signal has no significance as the filters are the same in the two channels Fig 2 shows the curve form of an interrupted signal at 785 c/s, before and after amplification in the selective amplifier recorded after rectification and filtration with

100 c/s low pass filters in both channels (1) and (2) The curve form of a stimulus impulse is shown concurrently (3) The pulse shown is a rectified signal at 2500 c/s filtered only by the low pass filtering action of the recorder This means that the signal is distorted very little by the filters Below this a stimulus signal at 250 c/s is reproduced directly (4) The recorder used (Mingograf) is a two channel writing recorder in which a fine ink jet traces a curve on ordinary adding machine paper The frequency range of the recorder runs from direct current to 700 c/s The paper feed rate used was 20 cm/sec in latency measurements and 5 cm/sec in registration of waves in the muscle contraction The impedance measurement apparatus gives a sound pressure of about 75 db re 0 0002 dyne/$cm^2$ This is measured with subjective comparison

*b* The same equipment was used in measurement of absorption as a function of the stimulus intensity, except that the output of the microphone was measured directly in amplitude relation and phase relation to the voltage applied to the telephone The voltage (E) from the microphone is in the following relation to the acoustic impedance $Z_m$

$$Z_m = k\,E\,, \qquad Z_m = \frac{Z\;Z_1}{Z+Z_1}\,, \qquad Z = \frac{Z_m\,Z_1}{Z_1 - Z_m}\,,$$

and by using admittances

$$Y_m = \frac{1}{Z_m} = \frac{1}{kE}\,,$$

$$Y = Y_m - Y_1\,, \qquad \left(Y_1 = \frac{1}{Z_1} \text{ and } Y = \frac{1}{Z}\right),$$

The energy absorption *a* and the angle of reflection coeffecient *R* are determined from

$$\sqrt{1-a}\;\, e^{j\varphi R} = \frac{\dfrac{1}{Y\varrho c} - 1}{\dfrac{1}{Y\varrho c} + 1} = -\,\frac{Y\varrho c - 1}{Y\varrho c + 1}$$

or

$$\sqrt{1-a}\;\, e^{j\varphi R} = \frac{\dfrac{Z}{\varrho c} - 1}{\dfrac{Z}{\varrho c} + 1}\,,$$

$$a = 1 - \left|\frac{Y\varrho c - 1}{Y\varrho c + 1}\right|^2$$

where Z is the impedance of the ear and $Z_1$ is the internal impedance of the microphone-telephone unit The impedance of the ear is measured in the plane of the microphone The absorption is most easily determined with the help of a bipolar chart in which both impedance and admittance may be used The use of admittances is advantageous because when admittances rather than impedances are used, the only effect of the internal impedance of the microphone-telephone unit is to shift the axes In order to obtain the impedance of the ear in the plane of the tympanic membrane it is necessary only to subtract the number of degrees corresponding to the length of the tube from the microphone to the membrane The absorption in this bit of tube is so slight that it may be disregarded

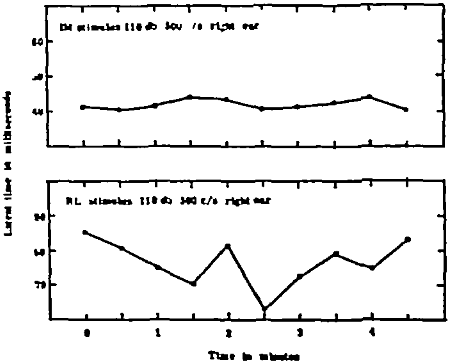

Fig 4 The variation in latent time for a series of 10 measurements made one every 30 seconds

## MEASUREMENT OF THE LATENT PERIOD

Eight persons, ranging in age from 18 to 32 years, and all with normal hearing, were examined The experimental subject was seated in a chair in a sound-insulated room The stimulus was applied as a rule, to the right ear, and the impedance measuring unit was connected to the left ear Fig 3 shows the arrangement The tube from the impedance measuring device was introduced into the ear Vaseline was used to insure an airtight connection between the tube and the auricular canal In measurements of the latent period a stimulus about 125 msec in duration was applied every 30 seconds At least ten measurements were made at each intensity It has been demonstrated that the latent period is not constant In a series such as the one studied here, wide variations may be obtained (see Fig 4) It was for this reason that several measurements were made at each in-

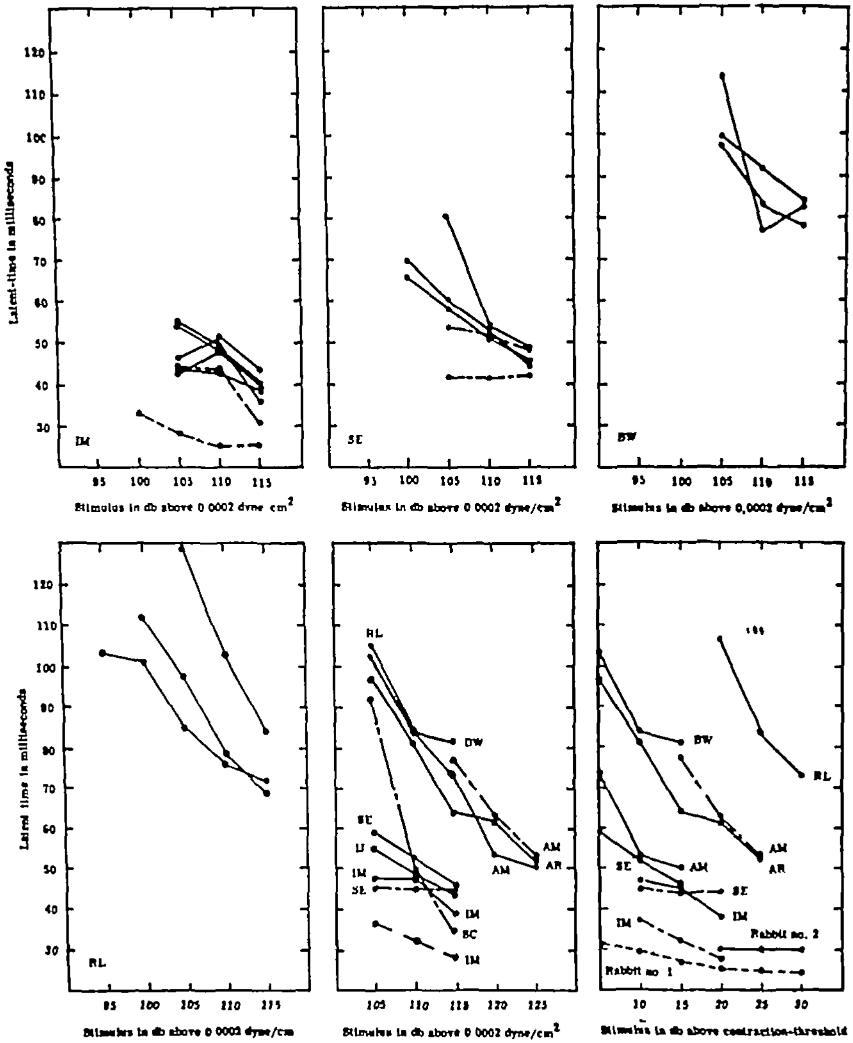

Fig 5 The relationship between latent-time and stimulus intensity for different persons Stimulus 1500 c/s broken line Stimulus 500 c/s solid line

tensity rather than only one for each stimulus intensity The latency has been defined as the mean value from a series of at least ten measurements Immediately after, the next series of measurements was started, with the lowest intensity first, succeeded by increasingly higher intensities This procedure was followed to avoid adaptation The stimulus frequencies used were 500 and 1500 c/s The test tone used for impedance measurement was not interrupted between measurements

Fig 5 shows the relation between the intensity of the stimulus and the latent period and the reproducibility of such measurements The different curves were recorded at intervals of several days It is evident that there is great variation from person to person The latency decreases as the stimulus increases at the same time that the reproductivity

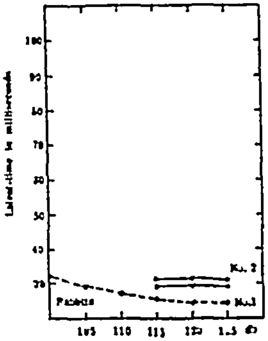

Fig 6 The relationship between latent-time and stimulus intensity for two rabbits (there is no reference here between the cited intensity and 0 0002 dyne/cm²)

of the measurements from day to day has a tendency to improve. The maximum and minimum latent time obtained was 130 and 25 msec It appears that 1500 c/s stimuli gave a shorter latent period than 500 c/s The intensity shown is re 0 0002 dyne/cm$^2$, measured in a 6 cc coupler, with the exception of the lower curve on the right (see Fig 5), where an attempt has been made to give the intensity relative to the threshold of muscle contraction This is rather unreliable, however, as the threshold value does not seem to be well defined, i e, the threshold is much higher before a contraction than shortly after The threshold discussed here was measured after a contraction caused by a tone somewhat higher than the threshold value

In measurements on rabbits the same technique was used as that employed in the measurements on human subjects, except that a tube was mounted on the telephone to carry the sound down into the rabbit's ear Moreover, 2000 c/s was used as stimulus frequency (see Fig 6) The tube on the impedance measuring unit was also longer The rabbits were placed on a table and held in a cloth bag An assistant held the telephone and impedance measuring unit in position The rabbits were not anesthetized The stated intensity of the stimulus was not re 0 0002 dyne/cm$^2$ in the measurements on rabbits because of the tube mounted on the telephone

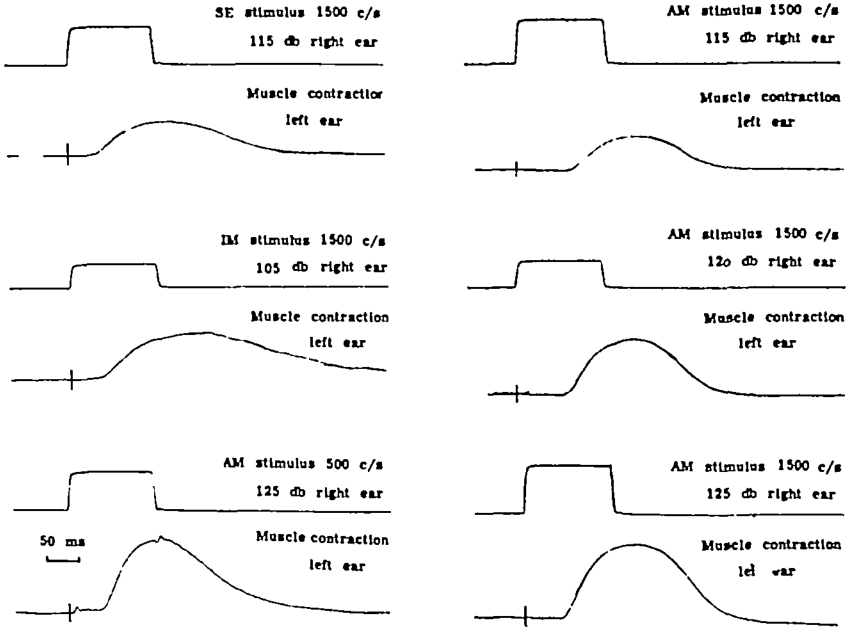

Fig 7 Examples of recorded muscle contractions

Fig 7 shows examples of the muscle contractions produced by the different intensities and in different persons The upper curve shows the stimulus and the lower curve shows the rectified signal that results from a muscle contraction The deflection shown need not be in any definite relation to the degree of muscle contraction This is because the registered signal occurs as the difference between the adjustable voltage and the output voltage of the microphone There is no simple relation between the output voltage of the microphone and the impedance or absorption of the ear. All that can be said is that when the microphone voltage changes it is due to a change in the impedance of the ear, and that may be due to a muscle contraction. It is not entirely impossible that a muscle contraction may take place without a change in impedance. Whether or not such a muscle contraction without a change in the impedance may be of any significance for sound transmission in the ear is uncertain.

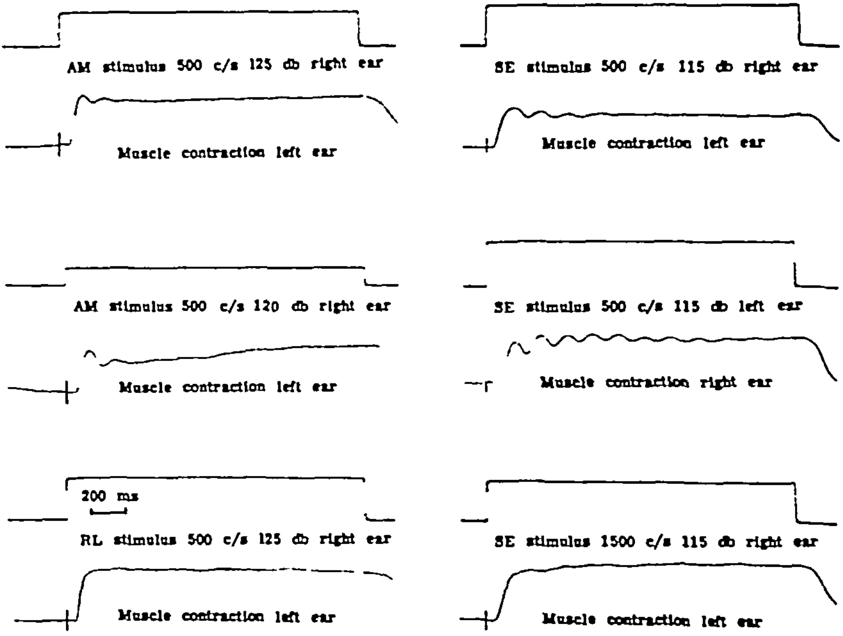

Fig. 8. Examples of recorded muscle contractions with waves in the beginning of the contraction.

Lorente de No has demonstrated in experiments on rabbits that waves occur with constant frequency in the muscle tension when the tensor tympanic contracts. A similar phenomenon was observed in three of the experimental subjects in this study, and was most pronounced in SE. The waves were not apparent in stimulation with 1500 c/s, but were a constant phenomenon with stimuli at 500 c/s in these three persons. Fig. 8 shows examples of such waves. The frequency was relatively constant and was about 7 c/s. (Lorente de No observed 15 and 20 c/s in rabbits ) The measurements in this case were carried out according to the same principles as the latent period measurements The mean values of the ten measurements were

| | |
|---|---|
| SE stimulus—110 db 500 c/s right ear | 6 4 c/s |
| SE stimulus—110 db 500 c/s left ear | 6 6 c/s |
| SE stimulus—105 db 500 c/s left ear | 6 9 c/s |
| AM stimulus—120 db 500 c/s right ear | 7 4 c/s |
| AM stimulus—120 db 500 c/s left ear | 7 5 c/s |
| IM stimulus—110 db 500 c/s right ear | 6 8 c/s |

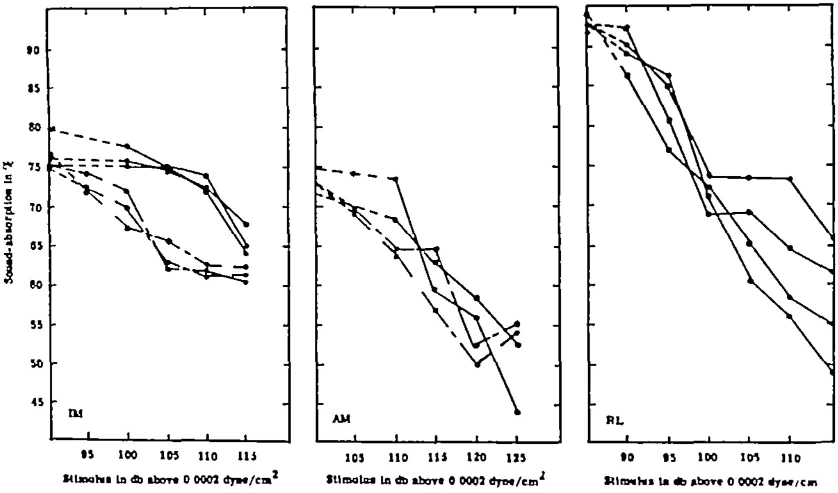

Fig 9 The relationship between stimulus intensity and sound absorption in the ear The broken lines are for stimulus 1500 c/s and the solid lines are for stimulus 500 c/s The points on the Y-axis which are connected with dotted lines to the curves indicate absorption without stimulus

Measurements on different days show that the reproductivity was extremely good

The experimental subjects remarked spontaneously that the stimulus tone was not constant in amplitude at the beginning of the stimulation when 500 c/s was used They heard a distinct change in amplitude on the occasions when waves were registered in the impedance change The persons who did not exhibit these waves could not hear variations in the amplitude, not even when they had been instructed to listen for them

Fig 9 shows the sound absorption as a function of the intensity of the stimulus for three different persons, measured in the external auditory canal with a measuring frequency of 785 c/s The different curves come from measurements on different days The first is the lowest stimulus intensity used, followed by the next lowest and so on The impedance changes in a muscle contraction appear to be a change in absorption without a change in the angle of the reflection co-efficient The measurements show that a muscle contraction causes a decrease in the sound absorption, which takes place gradually as the stimulus increases

## SUMMARY

The latent time for the contraction of the intra-aural muscles is measured in eight persons with normal hearing The muscle contraction is demonstrated with impedance measurement The latent time is defined as the mean of at least ten successive measurements at 30-second intervals A wide variation in the results was obtained with respect to measurements, both on different persons and on the same person, with intervals of several days between measurements For comparison, similar measurements were carried out on two rabbits A phenomenon worthy of note was the observance of waves in the muscle contraction in three of the experimental subjects during stimulation at 500 c/s The relation between the stimulus intensity and the sound absorption is investigated in three experimental subjects These studies demonstrate that the muscle contraction causes a decrease in the sound absorption without a change occurring in the angle of the reflection co-efficient and that the decrease in absorption occurs gradually as the intensity of the stimulus increases

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## AMERICAN BOARD OF OTOLARYNGOLOGY

The American Board of Otolaryngology will conduct only one examination in 1958, and this will be October 6-9, 1958, in Chicago, Illinois, at the Palmer House

For further information address Dr Dean M Lierle, Secy-Treas, University Hospital, Iowa City, Iowa

# A CASE OF UNUSUAL CONGENITAL FISTULA OF THE AURICLE

JOHN KEOHANE M B ,

STETTLER, Alta, Canada

The detailed and informative article (Skokan) on the entire subject of congenital auricular fistulae in THE LARYNGOSCOPE of September, 1957, brings to my mind an unusual case I recently treated

My patient, a female, aged 31, had a history dating back many years She had several operations some mere incisions with drainage of recurrent infected cysts, others, more determined attempts to irradicate her annoying and painful complaint

She was not quite sure whether her trouble first started in the concha or post auricular region When I first saw her she had a sinus that extended from the post auricular region to the junction of the concha and the floor of the external auditory canal She informed me that it discharged thick pus continually, and was liable to recurrent attacks of acute inflammation with considerable pain, discomfort, etc Gentle pressure with the finger-tip over the concha caused pus to present both anteriorly and posteriorly This also caused acute pain, and the area where the sinus opened in the concha was very tender indeed This, to my mind, indicated involvement of the perichondrium and cartilage of the concha, furthermore, the conchal sinus was surrounded by an area of necrotic looking skin about 1 cm in diameter, and the post auricular area was also quite unhealthy looking and scarred from repeated surgery

The problem was to cure the disease and preserve the appearance of the auricle as much as possible I thought of injecting the sinus with radio-opaque oil, but saw little point in it

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## AMERICAN BOARD OF OTOLARYNGOLOGY

The American Board of Otolaryngology will conduct only one examination in 1958, and this will be October 6-9, 1958, in Chicago, Illinois, at the Palmer House

For further information address Dr Dean M Lierle, Secy-Treas, University Hospital, Iowa City, Iowa

# THE ABSORPTION OF TOPICALLY APPLIED TETRACAINE AND COCAINE*

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## LOCAL ANESTHETICS

Local anesthetics rank high in the list of drugs which cause unnecessary deaths. Those who consistently use local anesthetics are familiar with their hazards; occasional users are often less versed in their pharmacology, toxicology and technique of use and usually experience the majority of difficulties.[1] The protocols of mishaps indicate that reactions and fatalities are most frequent after topical application. The otolaryngologists, in our experience, presumably because they use these drugs continuously and have respect for their potency, appear to encounter fewer difficulties.

The problem of reactions following the topical use of local anesthetics was of such concern that, in 1924, a commission was delegated by the American Medical Association to review the status of the then available drugs and make recommendations concerning dosage and technique of usage.[2] Although the situation has improved slowly since submission of their report, preventable deaths are still frequent. Seevers[3] has commented that more people die from local anesthetics than from any other group of drugs. Perhaps the problem is ignored, because the deaths occur sporadically, in many areas in the hands of many users.

Conflicting statements appear in the medical literature concerning absorption of local anesthetic drugs after topical application. Nearly everyone assumes that they are rapidly absorbed into the blood stream and that the high blood level

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After considerable thought it was decided to attempt a radical removal of the diseased tissue with subsequent skin grafting of the defects A plan was devised to preserve the appearance of the auricle at operation

Under general anesthesia a more or less circular incision was made surrounding the diseased conchal skin The lateral part of this incision was carried laterally through the incisura intertragica, then caudally and posteriorly, and finally in a circular manner to surround the diseased post auricular region This area was about 2 cm in diameter I might add that before the incision was made the posterior sinus was injected with Methylene Blue and the dye presented in the conchal sinus The incision was deepened to expose the entire sinus tract The supero-medial part of the sinus was surrounded by necrotic cartilage, and the circular incision was deepened to excise this cartilage The entire tract was then excised with the attached upper and lower diseased skin and cartilage The exact location of the postero-inferior end of the sinus was medial to the lobule over the lower part of the lateral surface of the mastoid process The dye was a very useful guide to the depth and location of the sinus The base of the wound was then curetted thoroughly

The area was repaired as follows

A split-thickness skin graft was cut from the medial aspect of the left thigh and used to repair the conchal and post auricular defect The incision through the incisura intertragica and the attachment of the lobule to the skin of the face was then sutured The conchal graft was made to fill its uneven bed with one-half inch vaseline gauze The posterior area was dressed with non-sticking "Telfa" The entire area was left untouched for two weeks, and removal of the dressings showed that the grafts had taken very well indeed

I have kept the patient under observation for several months, she has an execllent cosmetic result with no recurrence of any infection, and the grafts have survived exceptionally well Her auricle looks normal and its configuration was not changed in any way by the operation This is, of course, important, especially in a female patient ably lower than those obtained after a single application Identical blood levels were obtained if the total weight applied to a given area remained constant, even though the concentration was varied from 2 to 4 per cent This is extremely important, because it indicates that the blood level is more dependent upon total dosage than concentration The blood level was not detectable when 6 mgm per kilogram of tetracaine in the form of a 0 1 per cent solution was infiltrated subcutaneously over an area of the abdomen 3 x 4 cm The slow intravenous infusion of 6 mgm per kilogram ( 001 per cent solution) over a 20 minute period, likewise, caused no detectable quantity in the blood after the injection was complete

When the free base was precipitated and applied to the mucous membranes, the blood level curves were identical to those obtained when comparable weights of the base in aqueous solutions of the hydrochloride were used Absorption of the hydrochloride, incorporated in a water soluble cream base, applied to mucous membranes was prompt and rapid and occurred with ease These data indicate that the topical application of a given dose of a local anesthetic results in blood levels similar to those obtained after rapid intravenous injection The epithelial surfaces of the pharynx, trachea, alveoli and posterior urethra provide excellent absorbing surfaces Drugs are readily absorbed from the pulmonary alveoli because the osmotic pressure relationships in the pulmonary vascular bed are designed to prevent collection of fluid in the sacs Volunteers inhaling nebulized 4 per cent cocaine hydrochloride immediately experienced the stimulation characteristic of this drug and felt no appreciable numbness in the upper respiratory passages

Similar studies were carried out using cocaine The data closely follow the pattern of absorption obtained with tetracaine The statement is heard that 10 per cent cocaine is less toxic than more dilute solutions, such as the 4 or 5 per cent, because the vasoconstrictor effect is more intense with the more concentrated solution and absorption is retarded In order to determine whether or not this reasoning is correct, benzocaine crystals were incorporated in a 10 per cent is the direct cause Still, blood level studies to substantiate this assumption are not available Eggleston and Hatcher[1] indicated the role of rapid absorption in causing reactions but reported no blood levels Seevers and his co-workers,[2] studying the metabolism of cocaine, injected the drug subcutaneously, intravenously and into the stomach, but did not study absorption from the pharynx, trachea, bronchi and other mucous surfaces where it is used most often clinically

We felt that blood level studies might provide a clue to the cause of the high reaction rate and undertook such a study For obvious reasons, the study was done in the laboratory on dogs Blood levels were determined after the application of tetracaine and cocaine, the two most serviceable and widely used drugs, to the mucous surfaces of the pharynx, trachea and bronchi These blood levels were compared with those obtained after rapid intravenous injection, subcutaneous infiltration and slow intravenous infusion The rapid intravenous injection of 6 mgm per kilogram of tetracaine gave levels averaging 100 mgm per ml within one to two minutes The same quantity spread over the pyriform fossae or instilled into the trachea resulted in peak levels of 30 mgm per ml The peak was attained within four to six minutes The peak blood level was not so high, nor was it attained as abruptly, as that noted after rapid intravenous injection, but was far greater as compared to blood levels resulting from infiltration There is some difference between the curves obtained after the pharyngeal and intratracheal instillations, however, it is not remarkable, and the peak levels of both curves far exceed those after subcutaneous injection or slow infusion Epinephrine added to 2 per cent tetracaine did not retard absorption significantly The blood levels did not differ remarkably from those obtained without the use of epinephrine

In one set of experiments the total dose was doubled and applied in fractions at equal intervals of one minute over an eight to ten minute period The blood level gradually attained a peak of 20 mgm per ml after ten minutes The application of the drug in fractions resulted, as one would expect, in a gradual rise in blood levels The blood levels were consider-

Tetracaine is ten times more potent than procaine on the milligram for milligram basis, thus one mgm of tetracaine should produce the same degree of blockade as 10 mgm of procaine. On theoretical grounds, one would use 1/10 as much. Ordinarily one gram of procaine is the maximum quantity recommended for infiltration in an adult. On such a basis, it would follow that 100 mgm of tetracaine would be the maximum used for infiltration. In topical anesthesia, however, this does not apply necessarily because the absorption after topical application to the mucous membranes is far more rapid than after subcutaneous injection. The total quantity, therefore, should be much less than that suggested for infiltration, how much less is difficult to say.

Carabelli has attained adequate anesthesia using a 0.25 per cent solution of tetracaine. He suggests 20 mgm as the limit to be applied in fractional doses. Rubin and Culley[6] suggest 50 mgm as the limit to be applied in fractions over a period of 15 or 20 minutes. Weisel and Tarrow[7] using quantities not exceeding 40 mgm in 1000 endoscopy procedures noted 19 reactions. Seven of these were convulsive, the remainder were classified as mild circulatory. In the series of fatalities reported by the writers,[1] doses as high as 180 to 200 mgm had been used in some cases. Obviously, these doses were excessive and presumably accounted for the difficulties. Cocaine is approximately five times more toxic than procaine, thus, on theoretical grounds, the maximum amount of cocaine, at any one sitting, should not exceed 200 mgm. The question as to the maximum amount of tetracaine or cocaine to be used topically is not easily answered. These data on absorption seem to indicate that the dictum "use the least amount of the most dilute solution to obtain effective anesthesia as possible" should be adopted.

There is a latent or lag period from the moment a drug is applied to a nerve fiber until the full effect is established. This is especially true when topical anesthetics, such as cocaine and tetracaine are being employed. As many as five, and often as long as ten minutes may elapse before full anesthesia is obtained. Clinicians are either unaware of this latent period, or become impatient and tend to ignore it and

and a 4 per cent aqueous solution of cocaine and applied to the pyriform fossae Should cocaine produce a vasoconstriction it should retard the absorption of benzocaine Blood levels in each case were identical to those obtained when benzocaine was suspended in distilled water When benzocaine crystals suspended in water were applied to the pharynx after first spraying with 05 norepinephrine to the point of blanching, blood levels averaging 80 mgm per ml were obtained after five to nine minute intervals with a gradual decline to the zero level after 20 minutes Although these blood levels are somewhat lower than those of the control, and the peak is attained after a longer time interval, the difference is not so great that it is remarkable

It appears that neither the vasoconstrictor effect of norepinephrine or of cocaine is sufficient to suppress appreciably the absorption of benzocaine from the mucous membranes After the application of 100 mgm of cocaine as a 4 per cent solution to the pyriform fossae the blood level rose to 8-12 mgm per ml within 4 to 6 minutes and gradually receded to undetectable levels within a period of 15 minutes The same weight of cocaine as a 10 per cent aqueous solution applied to the pyriform fossae gave curves nearly identical in contour to those of 4 per cent cocaine The peak was attained within six to eight minutes, and the maximum value was 10 mgm With 4 per cent the maximum rise was within four to six minutes and rose to 8 to 12 mgm , thus, even though some cocaine causes vasoconstriction this effect is insufficient to retard absorption significantly When cocaine was combined with epinephrine nearly identical absorption curves were obtained These were not remarkably different from those obtained with 4 per cent alone

Dibucaine and tetracaine are the most potent and most toxic of the local anesthetics which possess suitable topical actions Procaine, the least toxic local anesthetic drug in current use, is devoid of topical action From the standpoint of effective topical anesthesia, one must concede that tetracaine is the most serviceable, however, one wonders whether he is justified in using it because of its toxicity The term *potency* applied to a topical anesthetic is not easily defined ly characteristic of a drug occurs  Idiosyncrasy is rare  Reactions characterized by hypotension, convulsions, excitement, coma, respiratory failure, etc , are not due to idiosyncrasy These are symptoms ordinarily anticipated from overdosage Idiosyncrasy is often confused with intolerance  Intolerance is a quantitative response  When a reaction is due to intolerance the usual response expected of the drug occurs, but with a quantity far less than the usual therapeutic dose  Intolerance also is uncommon but occurs more frequently than allergy or idiosyncrasy  It may be encountered in aged, poor risk subjects who are unable to metabolize the drug at the usual rate

The tendency to implicate allergy as the cause of reactions is all too prevalent  Many drugs, local anesthetics included, combine with protein and become antigenic. There is a remarkable difference between symptoms caused by overdosage and by an allergic response  When the response is an allergic one, eczema, urticaria, laryngeal edema or bronchospasm develop  These symptoms, particularly those manifested by cutaneous lesions, require some time to develop  Several hours may elapse before they appear, and they persist for several days  An allergic response implies that there has been previous contact with the drug, which invariably is the case  Such sensitivity may be detected by the use of patch tests or raising intradermal wheals  It is possible for a fatal reaction to be anaphylactoid, but this is rare indeed A minute amount of a drug applied topically intracutaneously, or by any other route, promptly causes syncope and death The quantity ordinarily used for raising a skin wheal or for performing a conjunctival sac test may cause death  Intracutaneous or conjunctival tests are of questionable value They may detect the occasional patient who has become sensitized and is truly allergic, but they are no value in detecting intolerance, likewise they are of no value in determining who may develop an anaphylactic response  The quantity used to perform the test would be lethal to a truly sensitive subject

## SUMMARY

Fatalities and untoward reactions occur more frequently commence surgical manipulations before anesthesia is fully established The anesthesia is usually inadequate and a second application is often made before the first has had an opportunity to exert its effect It can be seen how such a practice could lead to overdosage As a rule the longer lasting drugs manifest a longer latent period

Most physicians are generally aware of the effects of over concentration of local anesthetics on the central nervous system Local anesthetics depress cardiac tissues, the myocardium may be so depressed that asystole results This depressant effect of local anesthetics has been utilized to decrease prophylactically cardiac irritability and obviate arrhythmias during thoracic surgery Local anesthetics also cause vasodilatation Severe degrees of hypotension may result when myocardial depression and vasodilatation occur simultaneously There is no reason to assume that both the circulatory and nervous systems cannot be involved simultaneously, particularly when overwhelming doses are used, in fact, this appears to occur in reactions from tetracaine

Should a serious reaction occur, one is faced with two emergency situations, respiratory failure and asystole if cardiac arrest is suspected immediate opening of the thorax and cardiac massage is indicated, if the heart has not stopped but the blood pressure is unobtainable, vasopressors, such as ephedrine, phenylephrine (neosynephrine) or methoxamine (vasoxyl) or similar drugs should be administered intravenously Artificial respiration must be instituted immediately and maintained throughout the period of apnea or inadequate ventilation Obviously one should not undertake the administration of local anesthetics in situations in which it is not possible to institute resuscitative measures immediately In other words, one should have available apparatus for performing artificial respiration

Most reactions are due to overdosage Certain reactions, however, cannot be ascribed to overdosage, and are due to other causes Most clinicians classify reactions as due to idiosyncrasy In idiosyncrasy the usual therapeutic dose of drug gives a qualitative deviation from the anticipated pharmacological response, in other words a response not ordinari-

# A TECHNICAL AID IN ADENOIDECTOMY*

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A great deal has been written in relation to the surgical technique of the adenoidectomy, and it is generally agreed that direct visualization of the nasopharynx is highly desirable.[1,2,3,4,5,6,7,8,9,10]

Adenoidectomy on one hand has been greatly facilitated with the development and wide acceptance of the self-retaining type of mouth gags and the use of the head-low position. The surgeon does not require assistants, and aspiration pneumonia has been reduced to a minimum. On the other hand the use of the self-retaining mouth gag and the head-low position have contributed to a poorer exposure of the nasopharynx, often resulting in incomplete adenoidectomy.

Several authors[1,7] have advocated the sitting position in preference to the head-low position for the performance of adenoidectomy. The entrance of blood into the tracheobronchial tree in this position is prevented by an endotracheal tube with an inflated cuff. The soft palate is displaced with the use of one of the different types of palate retractors available. Two assistants are required: one to move the head of the patient into different positions, and the other to keep the operative field clean by the use of suction.[1]

The dangers inherent in the sitting position under general anesthesia, we believe, have been minimized by its advocates when they state[7] that the only advantage of the head-low position is the prevention of the entrance of blood into the trachea. In other surgical fields in which the sitting position is frequently used, numerous devices have been introduced to prevent orthostatic hypotension.

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when local anesthetics are applied topically than when injected  It has been assumed that rapid absorption is the cause, but direct evidence in support of this contention is scarce  The writers have determined the blood levels of tetracaine and cocaine, in dogs, after the *1* topical application in the pyriform fossae, *2* trachea and bronchi, *3* after the rapid intravenous injection, *4* after the slow intravenous infusion, and *5* after infiltration into subcutaneous tissues

The quantity of drug which results in no detectable blood level when infiltrated subcutaneously gives levels, when applied topically, equal to one-third to one-half of those noted after rapid intravenous injection  Epinephrine did not retard the absorption of either drug  Four per cent cocaine and 10 per cent cocaine gave similar blood levels  The basic form was as rapidly absorbed as the solution of the salt

The absorption from mucous membranes is far more rapid than clinicians have realized and closely simulates slow intravenous injection

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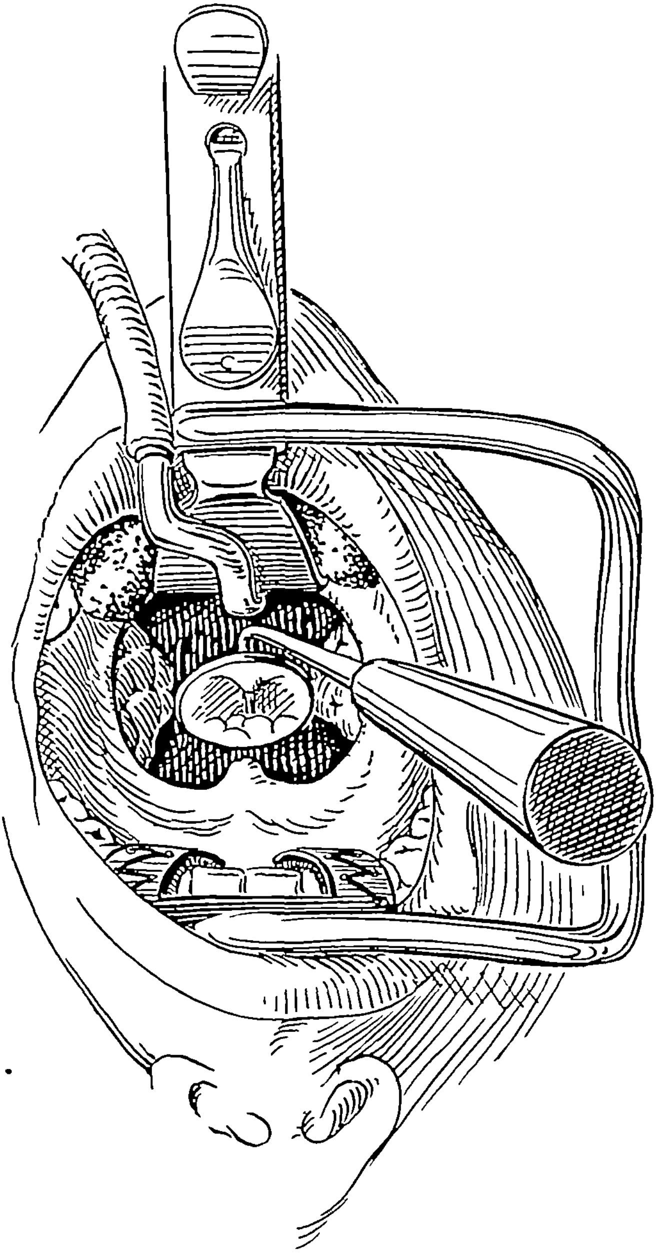


1.

Fig 1 A laryngeal mirror previously warmed in hot saline is placed in the oropharynx of the patient for indirect visualization of the nasopharynx.

It is well-known that passive tilt to the sitting position can be followed by hypotension even in normal subjects If the compensatory reflexes are impaired by the commonly used pre-anesthetic medications the postural hypotension is greatly increased[12] The hypotension may be followed by cerebro-vascular accidents We believe that this technique has definite advantages, but should not be used routinely because of the inherent dangers In cases of secondary adenoidectomies when there is a great deal of tension of the soft palate as a result of scarring, the erect position may be the procedure of choice and the only way in which a complete adenoidectomy can be performed

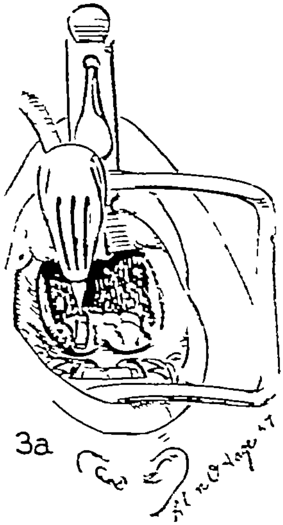
If an adenoidectomy is to be performed under direct visualization the self-retaining type of mouth gags should not be employed since they produce tension of the soft palate This makes exposure of the nasopharynx extremely difficult, and under these circumstances if the operator uses a palate retractor, lacerations of the soft palate will frequently occur

In our primary adenotonsillectomy we routinely use a self-retaining mouth gag and the head-low position A No 4 laryngeal mirror (see Fig 1) that has been previously immersed in a glass containing warm saline is placed in the oropharynx of the patient for indirect visualization of the nasopharynx

For the removal of lymphoid tissue from the nasopharynx various instruments can be used according to the needs of the individual case We prefer the Barnhill and Jones curettes,[11] the cutting edges of which should be kept sharp at all times The Meltzer punch forceps are especially useful for the removal of smaller collections of lymphoid tissue in the fossae of Rosenmueller The shanks of these instruments help in the retraction of the soft palate With one hand the laryngeal mirror is manipulated and with the other the cutting instrument

The main mass of midline adenoid tissue is removed with the first two or three strokes of the curettes The nasopharynx is kept free of blood with the Yankauer suction tube If bleeding interferes with further work in the nasopharynx by direct method[2] Because of the inverted image obtained the surgeon tends at first to make motions in reverse, but after the first few cases this initial difficulty is easily overcome

Caution should be taken when removing lymphoid tissue from the fossae of Rosenmueller with a curette or sharp dissection The mucosa of the medial side of the Eustachian tube should be left undisturbed otherwise adhesions will result from the healing of two opposite raw areas[9] (see Figs 3a and 3b)



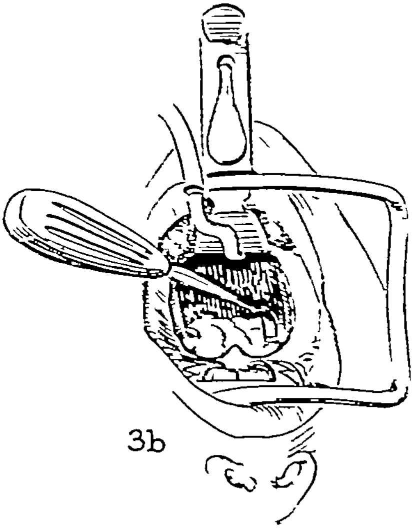
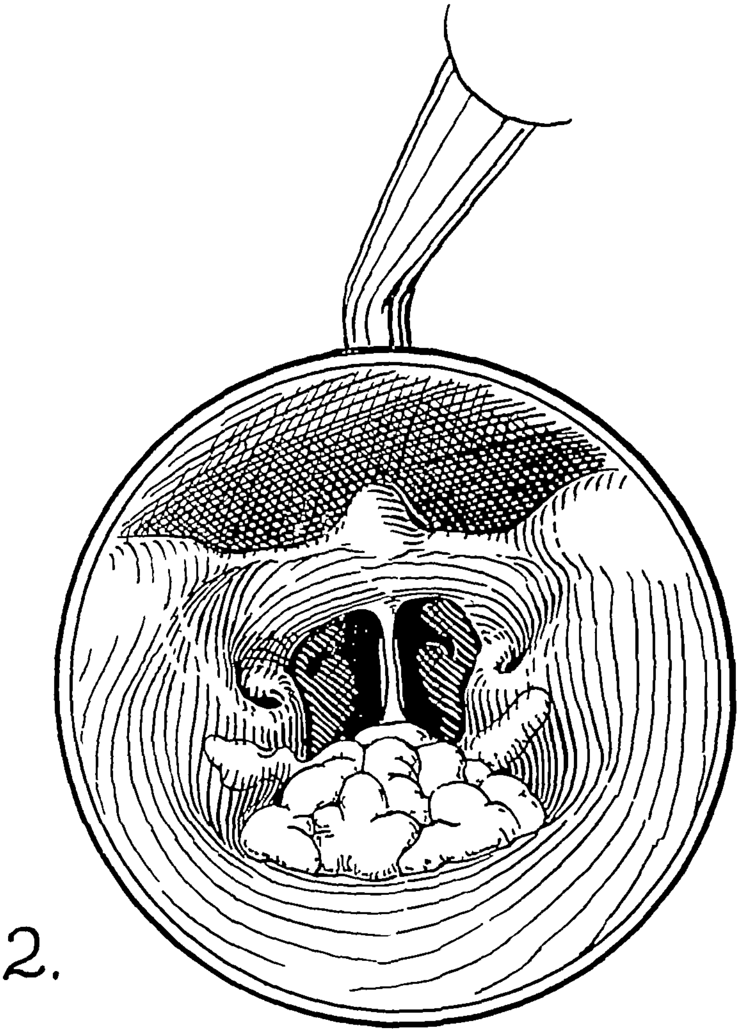


Fig 3a The correct position of the curette is illustrated The shank of the instrument is placed vertically avoiding the Eustachian tube

Fig 3b The curette is improperly placed If it is placed obliquely the posterior aspect of the Eustachian tube may be lacerated

A review of the literature showed that one author[13] had described the technique we have advocated A recent publication[14] also outlines a similar procedure The writer emphasizes the removal of the highest portion of the adenoids located immediately posterior to the choanae with a Takahaski forceps introduced through the nose and visualized with the laryngeal mirror placed in the oropharynx We have also practiced this procedure on several occasions, with satisfactory results



2.

Fig 2 Drawing of the nasopharynx as seen in the laryngeal mirror The soft palate is not shown in these figures

a post nasal pack is inserted, and the tonsillectomy is performed After its completion, attention once more may be directed to the nasopharynx, and any remnants of lymphoid tissue removed with the Meltzer punch forceps

We have been using this technique for the past five years with very gratifying results The view obtained by the indirect method (see Fig 2) is inverted from that obtained

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## OTOLARYNGIC RADIOLOGY COURSE

The Departments of Radiology and Otolaryngology, College of Medicine, the Ohio State University, will offer a postgraduate course in otolaryngic radiology February 4 and 5, 1958, at University Hospital, the Ohio State University Health Center, Columbus, Ohio, under the direction of John F Holt, M D, Professor of Radiology, University of Michigan, Lewis Etter, M D, Professor of Radiology, University of Pittsburgh, Roderick Tondreau, M D, Professor of Radiology, University of Pennsylvania, Sidney Nelson, M D, Professor of Radiology, the Ohio State University

There will be lecture periods with time given for group discussion Dr Holt will discuss the esophagus, salivary glands, tracheo-bronchial tree, and skull proper Dr Etter will discuss the paranasal sinuses, nose and nasopharynx Dr Tondreau will discuss the mastoid and larynx

Registrants are encouraged to bring interesting roentgenograms for participation in discussion periods

A fee of $35 00 must accompany the registration application Luncheon for the two days will be included in this fee All registrations are to be completed by January 15, 1958

Address applications or requests for additional information to William H Saunders, M D, Department of Otolaryngology, University Hospital, Columbus 10, Ohio

The adenoidectomy should not be performed blindly or by palpation These methods should be delegated to the historical background of the operation, but its use in modern surgery should be condemned

## SUMMARY

*1* The sitting position should not be used routinely in the performance of the adenoidectomy because of orthostatic hypotension and possibly cerebro-vascular accidents

*2* A technique of indirect visualization of the nasopharynx is described

*3* This technique has been used in the past five years with encouraging results

*4* Blind methods in the performance of the adenoidectomy are condemned

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## SUBCOMMITTEE ON HEARING IN CHILDREN

The American Academy of Ophthalmology and Otolaryngology, through its Subcommittee on Hearing in Children of the Committee on Conservation of Hearing, has been conducting a long-term nationwide study of problems relating to the conservation of hearing in children The specific aims are to develop the most efficient case-finding methods and to use these methods in estimating the magnitude of the problem in the country, to study state laws and review current practices and facilities for rehabilitation of hearing impaired children, to help develop methods for medical and surgical rehabilitation standards, and ultimately to use the Subcommittee findings in assisting professional workers to improve and enhance programs in hearing loss

In the second year of operations, a full-time Executive Director has been engaged, and offices established at the Graduate School of Public Health, University of Pittsburgh An initial study is being conducted in Pittsburgh to identify early medical signs and symptoms which may indicate danger of hearing impairment, to measure the psychological, social and other effects of such impairment and to develop efficient and economical methods for the testing of hearing in children The Pittsburgh study is a cooperative effort among the following The Subcommittee on Hearing in Children, the Graduate School of Public Health and the School of Medicine of the University of Pittsburgh, the Pittsburgh Board of Public Education, and the Allegheny County Department of Health

The members of the Subcommittee on Hearing in Children are Dr John E Bordley, Baltimore, Dr Victor Goodhill, Los Angeles, Dr Hollie E McHugh, Montreal, Dr S Richard Silverman, St Louis, and Dr Raymond E Jordan, (Chairman) Pittsburgh An advisory committee of consultants from the University of Pittsburgh includes Dr Samuel M Wishik, Dr Leo G Doerfler, and Dr Isidore Altman Grants from the United States Children's Bureau through the Pennsylvania Department of Health and from the National Institutes of Health are providing financial support

# BOOK REVIEWS

**Sprachaudiometrie** Grundlagen und Praktische Anwendung Einer Sprachaudiometrie fur das Deutsche Sprachgebiet Doz Dr Med Karl Heinz Hahlbrock Georg Thieme Verlag Stuttgart (in the U S A. and Canada Intercontinental Medical Book Corporation, New York 16 N Y 1957 Soft cover 182 pp $5 00

Dr Hahlbrock has produced a comprehensive synthesis of the principles and practices relating to speech audiometry The chapters include the development of speech audiometry, the practical procedures interpretation of test results, comparisons between classical tests of hearing and speech audiometry and the techniques of application of speech audiometry to the selection of patients for surgery and the selection of hearing aids

For those who can understand the German language this should be a useful guide to speech audiometry There is a short introduction by Prof Dr F Zollner

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**Educational Guidance and the Deaf Child** Edited by A W G Ewing The Volta Bureau 1537 35th St N W, Washington 7, D C 1957 345 pp

A W G Ewing Professor and Director of the Department of Education of the Deaf University of Manchester, has brought together a collection of studies that reflect the activity in the Department of Education of the Deaf at his University The major portions of the volume deal with infancy and early childhood and children of school age A good deal of emphasis is placed on screening tests and guidance for parents and on tests of abilities and attainments The book is a useful compendium for those who want to acquaint themselves with the forward looking activities at Manchester

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**Look, Listen and Lipread** Edited by Betty C Wright The Volta Bureau, 1537 35th St N W Washington 7, D C 1957 Soft cover 110 pp

Miss Wright, who is listed as Consultant American Hearing Society and U S Office of Vocational Rehabilitation, Instructor of Lipreading Hearing Center, Medical College of Virginia has gathered together contributions from experienced teachers of lipreading that the latter have found useful in practice The compendium is a useful source of tried material for the teacher of lipreading

S R S

# THE 11TH CONGRESS OF THE INTERNATIONAL ASSOCIATION OF LOGOPEDICS AND PHONIATRICS

The 11th Congress of the International Association of Logopedics and Phoniatrics will take place in London, August 17-22, 1959 The following official reports will be presented The Inheritance of Voice and Speech Disorders, Prof R Luchsinger, M D, Zurich, Defects of Articulation, Muriel Morley, B Sc, F C S T, Newcastle, The Physiology and Pathology of the Soft Palate, Prof Lucio Croatto, M D, Padua The official languages of the Conference will be English, French, and German

Those working in the field of Speech and Voice Therapy and all who are interested in this specialty are invited to attend and to submit papers

If intending to be present, whether submitting a paper or not, please inform the Congress Secretary at the earliest possible date

Papers are invited on subjects relevant to the three main reports or any other aspect of speech and voice Only one contribution will be accepted from any one member of the Congress and this must not have been previously published The Committee reserves the right to select papers Papers should be restricted to 15 minutes in length, demonstrations to 10 minutes In special cases 20 minutes may be allowed for a paper of great importance but only if application is made at the time of submitting the title Should a group of four or more people wish to present a symposium or a prepared discussion on a theme, consideration will be given to allocating up to one hour for such a contribution

Titles must be received by September, 1958 Summaries must be received not later than November 15th, 1958

All communications are to be sent to Peggy Carter, L C S T, 46 Canonbury Square, London, N 1

## THE INTERNATIONAL CONGRESS ON THE EDUCATIONAL TREATMENT OF DEAFNESS

The University of Manchester Department of Education of the Deaf, will sponsor The International Congress on the Educational Treatment of Deafness, July 15-23, 1958

The Minister of Education for England and Wales has decided to recognize the Congress as a Short Course which teachers of the deaf may attend under Grant Regulations

An interesting program has been arranged

Demonstrations will be given to illustrate some aspects of the research that is in progress in the audiology unit and audiological laboratories of the Department of Education of the Deaf, and in collaboration with the Department of Otolaryngology, the Public Health Department and School Medical Service of the City of Manchester, and the Ear, Nose and Throat Department of the Royal Manchester Children's Hospital The subjects of the demonstrations will include procedures for the making of screening tests and assessments of the hearing of babies and young children, the results of guidance to parents to enable them to give home training to their children of pre-school age whose hearing is impaired, and the results of an experimental investigation on problems in architectural acoustics that concern the use of hearing aids in school buildings

Arrangements are being made to offer accommodation to members of the Congress in University Halls of Residence The cost of this type of accommodation is expected to be about £1 2s od per day, including bed, breakfast and dinner The University refectory will be available for meals during each day

For those members who wish to do so, arrangements will be made to visit audiology clinics and special schools in London, Oxford and other places In connection with the Congress it is hoped to organize tours to places of interest The dates proposed for this are July 9th, 10th, and 11th

For further details write Prof A W G Ewing, Department of Education of the Deaf, The University, Manchester 13, England

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THE

LARYNGOSCOPE.

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# FIXATION OF FRACTURES IN THE MIDDLE THIRD OF THE FACE, WITH KIRSCHNER WIRES*†

HERBERT H HARRIS, M D ,

Houston, Tex

There is an ever increasing number of fractures about the body as a result of violence, most of which are caused by traffic accidents Many of these are about the head and face, and not infrequently of the middle third Though fractures in the middle third of the face may be the only or principal injury, they do occur with other fractures, such as the mandible or long bones of the body, and many times with severe skull or brain injury

When fractures of the middle third of the face do occur with other injuries the picture is more complicated, and the other injuries may be of primary concern It is because of these severe injuries that facial fractures may either go unnoticed or ignored until late, enough so at times to make their primary reduction impossible

There are many things which must be taken into consideration before a fracture in the middle third of the face is reduced Severe or critical injury elsewhere may prevent the early reduction of these fractures, in fact, unless I can get them rather early, four or five or even ten days' delay seems to make little difference in the reduction, and with the use of antibiotics infection is no longer a hazard Even at the end

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*Read before the Section on Otolaryngology Sectional Meeting of the American College of Surgeons Feb 6 1957 New Orleans La

†From the Department of Otolaryngology Baylor University College of Medicine

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about the lacrimal bone and the lacrimal duct may cause tearing of the eye

The diagnosis of facial fractures is usually not difficult for one who is familiar with the landmarks Tactile sense of the trained index and middle fingers can always elicit deformity regardless of the swelling, unless infection has taken place and the tissues have become brawny As mentioned before, palpation of the nasal bones, the infraorbital ridge, the malar eminence of the zygomatic bones and the occlusion of the teeth are the points which, if in their proper position, almost always means either no fracture or displacement of the fractured bones

There are many positions for taking X-ray to determine the extent and location of fractures in this area, but due to the thinness of some of the bones and shadows cast by overlying bone I have never been satisfied with flat plates Usually, and I might say always, a good stereo in the Waters position studied thoroughly will give not only a clear picture of the nature and extent, but also will tell one the direction of the force which caused the fracture This is always very important to me, as a force for traction in the opposite direction to that causing the injury must be exerted to reduce the fracture

There are many methods of reducing fractures of the zygoma, as there are many methods used to fix other fractures I do not believe that one can use any one method for all facial fractures any more than one method only can be used for fixing fractures of long bones Open reduction and wiring of the fragments has its advantages as well as its disadvantages Packing a sinus to reduce a fracture of the infraorbital ridge and anterior wall of a sinus, when the zygomatic bone has been fractured and pushed into the sinus, is not always enough to insure good results The use of the Kirschner wire as a method of fixation is not the method I use in every case, but I do believe that it is the simplest and the most satisfactory when combined with other methods if necessary

The Kirschner wire (see Fig 1a) much like the Steinman of four weeks I have been able to reduce some of these fractures, for they heal by scar tissue, and at this time one can reduce them with some difficulty, mobilize the fragments for better alignment, but when there are small comminuted areas it is most difficult to replace these small fragments

The primary objective when a patient has these, combined with other severe injuries, is to preserve the life of the patient, since in themselves these fractures are rarely serious Shock, severe brain damage, chest and abdominal injuries must be treated first Hemorrhage from the broken blood vessels along the line of fracture is one complication which must be controlled early, regardless of the severity of injuries elsewhere Most bleeding can be controlled by packing the nose when such fractures extend through the nasal cavities, although other means must be resorted to when necessary

Airway obstruction may follow some severe injuries and a tracheotomy should be done without hesitation When lacerations of the face do occur in combination with these fractures they should be meticulously repaired early, even if it is impossible to reduce the fractures at the same time If the fracture is to be reduced within the first 24 hours, I recommend that the fracture be reduced first and the laceration repaired last, for sometimes in manipulation, the lacerated areas may be separated, and a good cosmetic result cannot be obtained

There are several anatomical landmarks which must be kept in mind as a guide to obtain the best result, the nasal bones, the infraorbital ridge, the malar eminence of the zygomatic bone and the occlusion of the teeth Of course, all of these may not be involved in every fracture, but they all must be restored to the original position if good function and good cosmetic results are obtained Even though the alveolar ridge with the upper teeth may not be involved fractures of the zygoma, the infraorbital ridge and the floor of the orbit may allow the eye to dip so that diplopia develops and even trismus due to the impingement of the coronoid process on the zygoma Fractures of the nasal bones, with displacement, may cause nasal obstruction and fractures pin but smaller comes in three sizes, 062, 045, and 035 of an inch, is made of stainless steel and can be drilled into the bone or through the bone without first making an opening Ipsen[3] described the use of the Kirschner wire in fixing fractures of the mandible in 1933 Brown, et al,[1 2] reported its use first in 1951 for fractures in the middle third of the face There is one important point to remember in using the wire. If a drill especially made for the Kirschner wire is not available, any hollow shaft drill can be used, but only about one-and-one-half to two inches of the wire should be allowed to extend beyond the end of the chuck (see Fig 1b) Allowing such a small amount of the wire to extend beyond the chuck prevents wobbling of the wire, and the direction of the drilled wire is more accurate In most facial fractures I have found the 062 or the heavy Kirschner wire to be the most satisfactory size

Though fractures may occur with much comminution, there are several which I believe rather completely typify most of these fractures of the middle third of the face Probably the most common injury is that to the nose and the frontal processes of the maxilla I shall not take this up in my discussion except insofar as it is related to other fractures in this region

Though no two fractures are alike, most are similar in that they may be classified into six general types

*1* Simple zygomatic fractures

*2* Zygomatic fractures with comminution of the infra-orbital ridge and anterior wall of the sinus

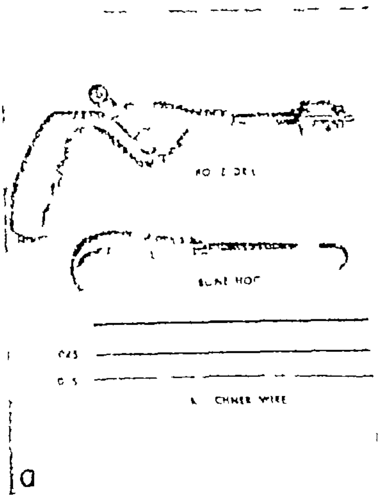
*3* Transverse fractures of the maxillae or LeFort I

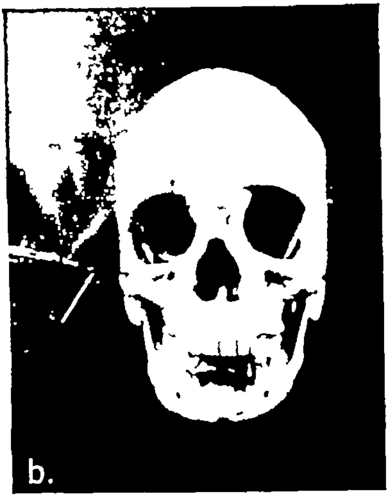
*4* Pyramidal fractures of the maxillae or LeFort II

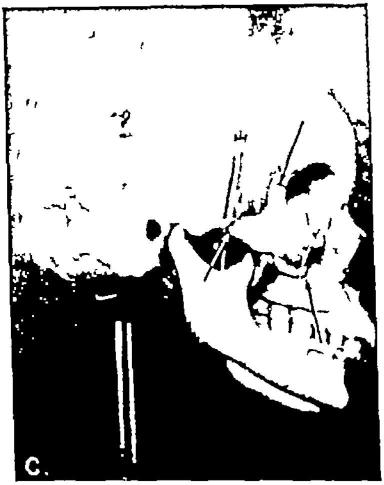
*5* Cranio-facial fractures of LeFort III

*6* Combination of some of the above with comminutions

Simple zygomatic fractures not infrequently may be reduced with the bone hook or some other device such as a towel clip, though occasionally I have been unable to reduce the fracture without entering the maxillary sinus when there







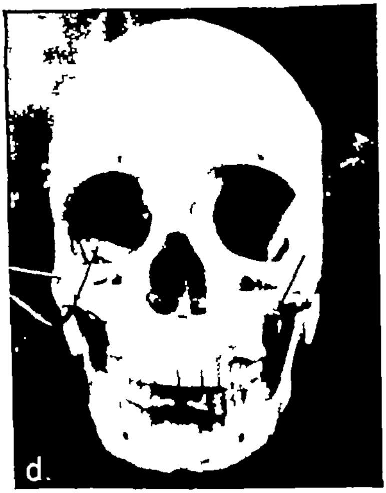
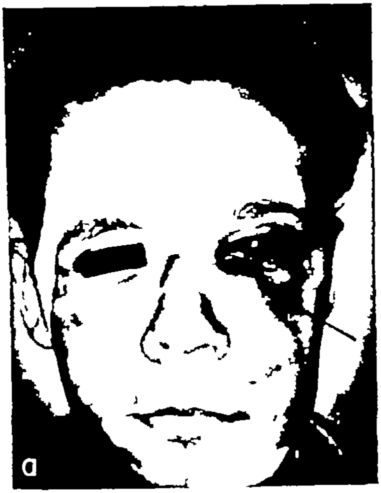


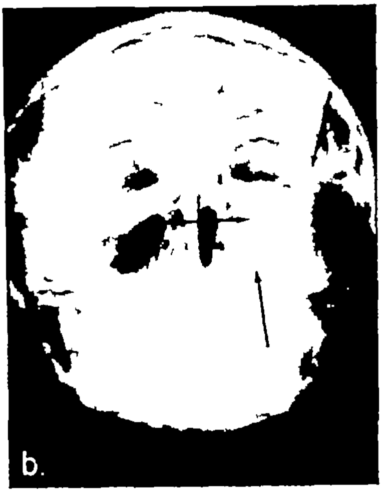
Fig 1a Ordinary bone drill bone hook and the three sizes of Kirschner wires

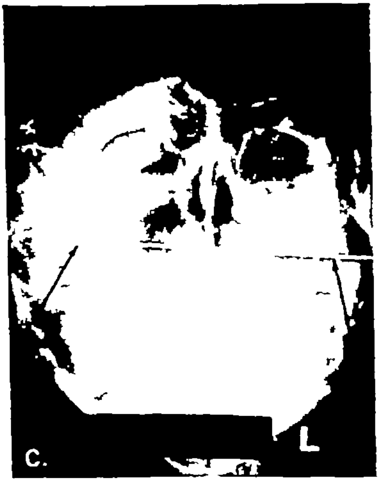
Fig 1b Only about 1½ to 2 inches of the wire are allowed to remain between the bone and the chuck of the drill to prevent wobbling

Fig 1c Fracture lines in simple zygomatic fracture

Fig 1d Shows the position of the bone hook to reduce a typical zygomatic fracture and the direction of the Kirschner wire into the other side







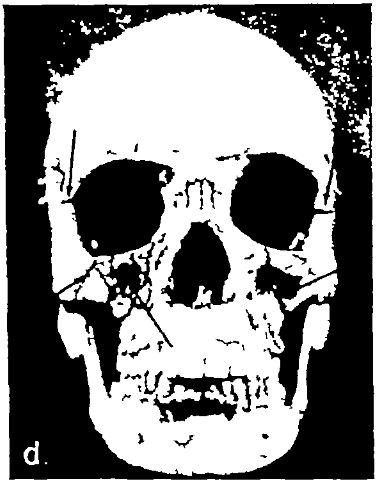


Fig 2a Typical depression over the cheek area in simple zygomatic fracture

Fig 2b Typical fracture lines Note the reduced size of the maxillary sinus due to the depressed zygoma.

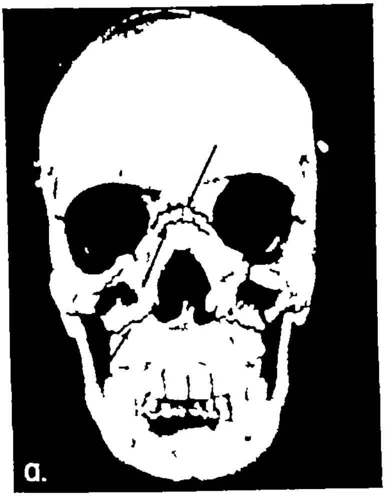
Fig 2c. Reduced fracture fixed with a Kirschner wire by fixing across to opposite zygoma.

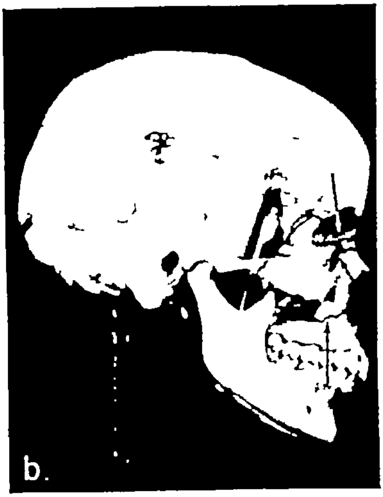
Fig 2d Right zygoma shows typical fracture lines with comminution of the infraorbital margin and anterior maxillary wall through the zygomatic arch and the frontal-sphenoid suture line area. Left zygoma shows typical fracture lines of the simple zygomatic fracture

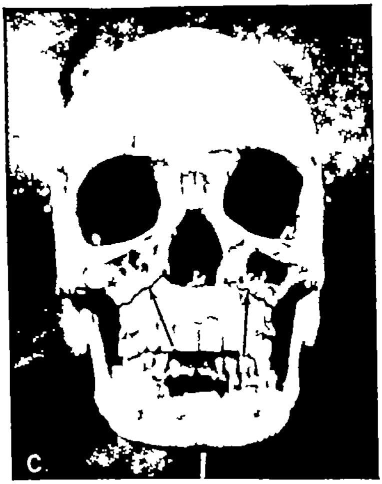
seemed to be impaction of the fragments I have not found it necessary to make an incision above the arch The fracture lines in a simple zygomatic fracture (see Fig 1c) usually occur in or near the suture line of the fronto-sphenoidal process with the corresponding bones, near the suture line in the zygomatic arch and through the anterior wall of the maxillary through the infraorbital foramen downward and laterally through the thin lateral wall of the maxilla

A large percentage of these simple fractures when reduced will remain in good position without fixation This depends materially on how much comminution there is at the fracture line If the zygomatic bone does not remain in good position, it can be held in place with the bone hook and a 062 Kirschner wire drilled through the body of the fractured zygoma into the medial maxillary wall across the nose, through the medial wall and into the lateral wall of the opposite maxillary just below the body of the zygoma (see Fig 1d) Formerly, I tried to drill the wire through to the opposite body of the zygoma, but this is not necessary as it does keep the wire away from the opposite orbit and the infraorbital nerve I have never seen an accident occur with the wire, but I am sure it would be possible for the wire to be deflected into the opposite orbit if one were not very careful when trying to fix the wire into the opposite body of the zygoma Passing through these several structures, the medial wall of both maxillary sinuses, the nasal septum and into the lateral wall of the opposite sinus, usually give sufficient support of the wire If a satisfactory reduction and fixation is not accomplished at first the wire may be withdrawn In difficult cases I have drilled it across to the opposite side as many as three or four times before getting a satisfactory position I have never seen any untoward results as it punctures the turbinate and is withdrawn There may be some bleeding which stops very quickly A case of simple fracture of the zygoma is herewith illustrated (see Figs 2a, 2b, 2c and 2d)

Comminuted fractures of the infraorbital margin and the anterior wall of the maxillary sinus, combined with a depression of the zygomatic bone into the sinus, poses a slightly greater problem in obtaining good results (see Figs 2d, 3a







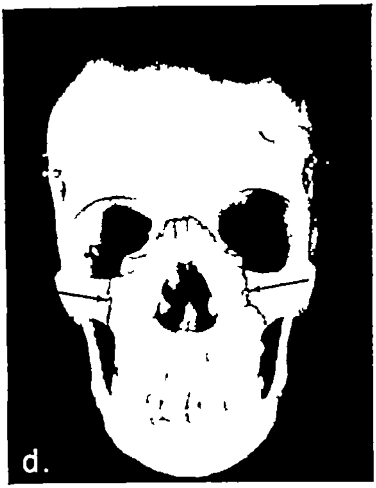


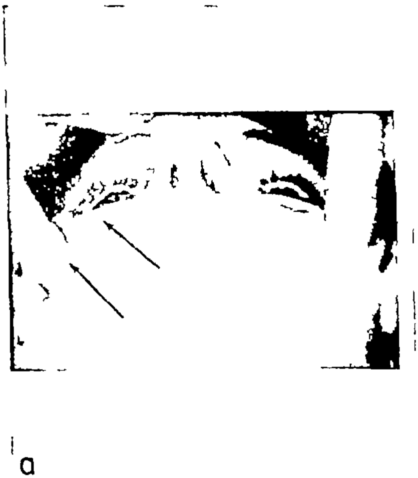
Fig 4a Typical lines of fracture transverse pyramidal and craniofacial from below upward Front view

Fig 4b Same Side view

Fig 4c Fracture lines transverse fracture of maxillae

Fig 4d Fracture lines pyramidal fracture of maxillae

and 3b) Entering the maxillary through the canine fossa region and making a counter opening into the inferior meatus for the purpose of removing the gauze packing is usually necessary I pack the sinus with one-half inch gauze impregnated with aureomycin ointment and replace and mold the comminuted fragments back into place, and suture the wound, bringing the gauze out of the opening in the inferior meatus



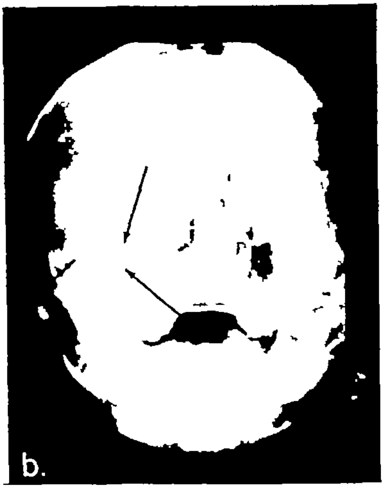
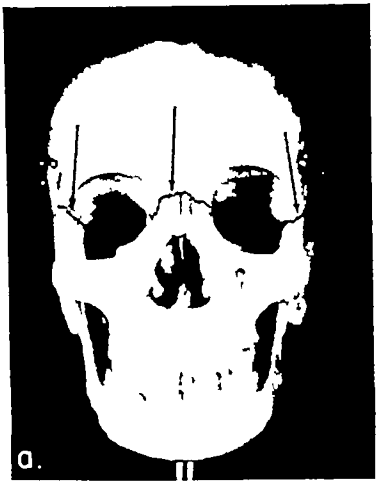


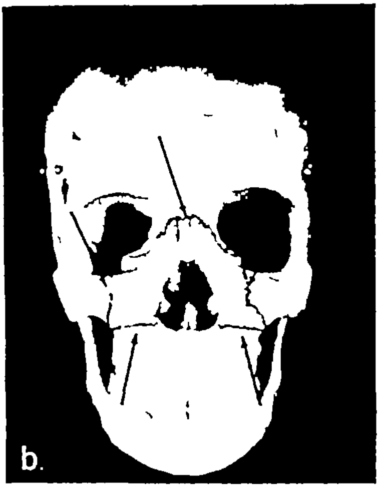
Fig 3a Typical appearance of the face in a fracture of the zygoma with comminution of the anterior wall of the sinus and the infroarbital margin

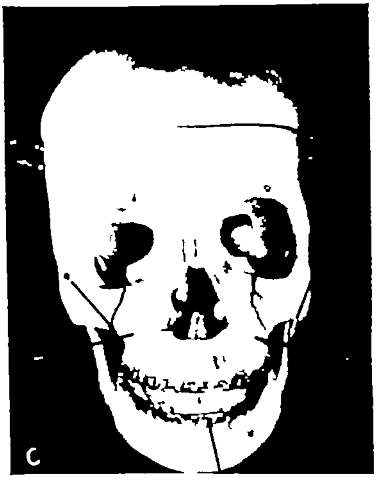
Fig 3b X-ray findings of the same patient showing the comminutions when stereo was viewed

The body of the zygoma, which usually is not comminuted, may be held in place as in a simple zygomatic fracture, passing the wire across the gauze filled cavity Of course, the gauze must be left in as long as the wire, which I find is usually 18 to 21 days

I wish now to take up the group of fractures known as the LeFort I, II and III, or the transverse, pyramidal and craniofacial features (see Figs 4a, 4b,) These have one factor in common The maxillae containing the teeth is fractured from the skull at different levels The teeth, therefore, do not occlude normally or properly Though the maxillae are







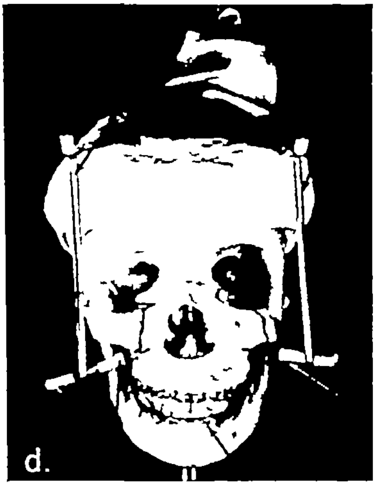


Fig 5a Fracture lines in cranio-facial fracture

Fig 5b Fracture lines in transverse and pyramidal fractures from below upward

Fig 5c. Pyramidal fracture of maxillae using Kirschner wires for cross wiring and direct fixation into opposite zygoma Fracture splints on teeth

Fig 5d Pyramidal fracture with wires withdrawn from opposite zygoma into maxillary sinus so that traction can be applied to head cap Fracture splints on teeth.

usually fractured downward and backward, occasionally the maxillae are pushed backward and upward

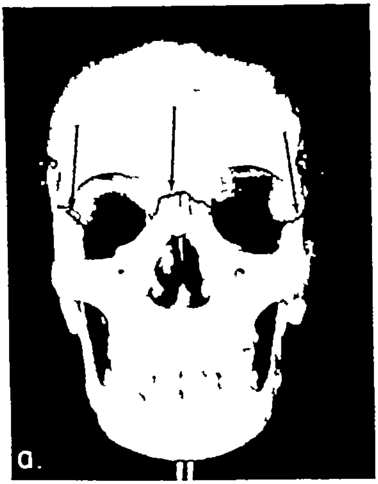
The transverse fracture occurs just above the alveolar margin so that the teeth, if they are present, are contained in the lower fragment (see Fig 4c) In my experience these are less common than the pyramidal, but likely occur when dentures are worn and the blow occurs over the dentures, causing a shearing injury

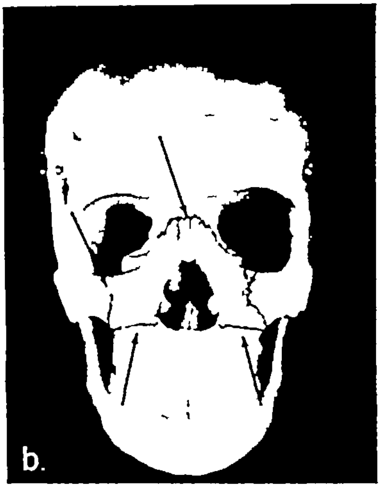
Pyramidal fractures occur a little higher up on the maxillae involving the nasal bones, the anterior wall of the maxillae and the infraorbital ridges, the floor of the orbit and the anterior and lateral wall of the maxillae, usually at different levels on each side (see Fig 4d)

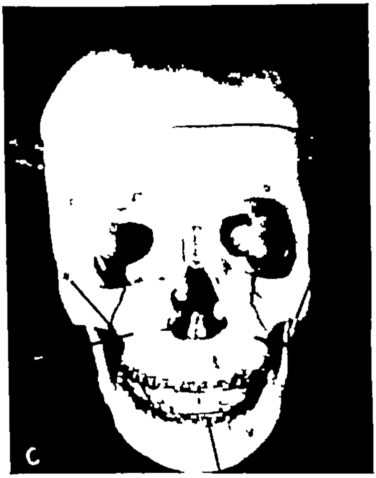
The cranio-facial fracture is at a still higher level through the ethmoid labyrinth into the posterior part of the inferior orbital fissure, near the suture line between the fronto-sphenoidal process with the corresponding bones and through the zygomatic arch (see Fig 5a) To secure and maintain proper occlusion of the teeth is one main objective If no teeth are present occlusion is not so important, but maintaining good position of the fragments is essential It must be remembered that a good cosmetic result can be obtained without perfect occlusion of the teeth, but good function requires perfect occlusion

In all of these fractures the airway may be of concern and a tracheotomy may be necessary immediately, or may be necessary when fracture splints or arch bars are applied to the teeth and the nose packed to reduce a fracture

Transverse and pyramidal fractures (see Fig 5b) may be treated by cross wiring the lower fragment into the body of the opposite zygoma, especially if no teeth are present (see Fig 5c) In pyramidal fractures, if most of the teeth are remaining and the nose fractured, I do a tracheotomy, then apply the fracture splints to the teeth and reduce the fracture and try to get good occlusion by cross wiring the lower fragment into the body of the zygoma, then finally and lastly reduce the nasal fracture In most cases I have found that the lower fragment is stable, but the occlusion is not perfect and I resort to







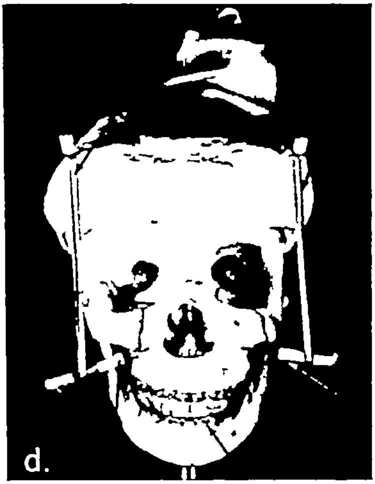


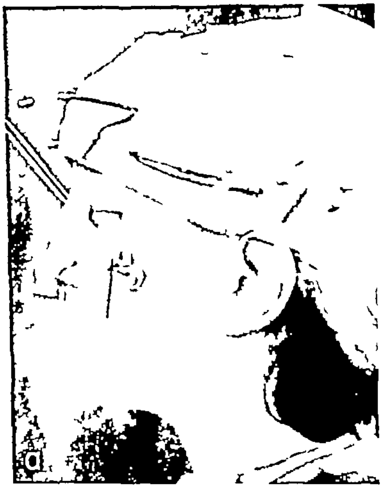
Fig 5a Fracture lines in cranio-facial fracture

Fig 5b Fracture lines in transverse and pyramidal fractures from below upward

Fig 5c Pyramidal fracture of maxillae using Kirschner wires for cross wiring and direct fixation into opposite zygoma Fracture splints on teeth

Fig 5d Pyramidal fracture with wires withdrawn from opposite zygoma into maxillary sinus so that traction can be applied to head cap Fracture splints on teeth

the head cap and traction with rubber bands after these wires have been withdrawn from the body of the zygoma (see Fig 5d) The traction is usually forward and upward as is shown in Fig 6a Sometimes when the fragment is pushed upward traction must be applied downward and forward Though flat plate X-rays show the fracture lines (see Fig 6b) a stereo in the Waters position gives much more detail The nasal



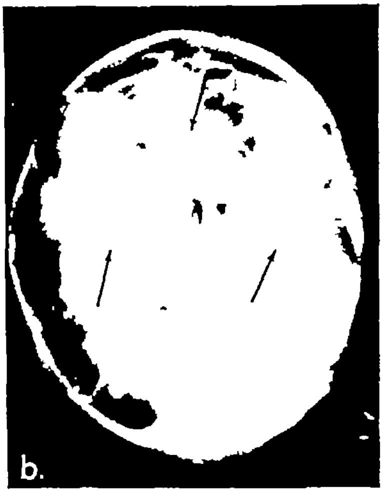


Fig 6a Pyramidal fracture with forward and upward pull of lower fragment

Fig 6b X-ray view Waters position showing typical pyramidal fracture

bones, when badly comminuted, should not be reduced until the maxillae are in good position, and then may be moulded into position a few days later if a good position is not secured at first I have found it very difficult to use one pin across the lower fragment, as not infrequently it will be deflected into the fracture line of the opposite side and no traction can be obtained on that side

Management of the cranio-facial or LeFort III type of fracture can be handled very much the same way as the transverse and pyramidal fracture, except that direct fixation cannot be done satisfactorily, due to the fact there is no adequately strong structure into which the wire may be secured It is then usually necessary, if open reduction is not done, to use the traction method, as well as fracture splints to the teeth

The use of head caps is certainly not the most satisfactory method of applying traction, but I have found none better Braiding the hair and then applying one of the "spray nets" to stiffen the hair helps some In my experience the mobile type of fixation with traction is worth the effort, because all of these patients get a good occlusion

## CONCLUSIONS

*1* Use of the Kirschner wire for direct fixation of fractures of the middle third of the face has been found to be very satisfactory

*2* Less time is required to fix fractures by this method than by open reduction

*3* Use of the Kirschner wire to which traction can be applied is most satisfactory and there is minimum scarring at the entrance through the skin

*4* The use of two Kirschner wires crossing into the body of each zygoma has been found more satisfactory than trying to cross directly from one zygoma to the other in fixation of pyramidal fractures and gives the added factor that the point can be withdrawn into each maxillary and traction applied with a head cap, if the reduction has not been satisfactory

*5* Where fracture splints to the teeth must be applied and the nose packed for reduction of an accompanying fracture, tracheotomy is advisable, preferably through a transverse incision

*6* No accidents or infections have been encountered thus far in my cases

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# ELECTROMYOGRAPHIC STUDY ON RESPIRATORY MOVEMENTS OF THE INTRINSIC LARYNGEAL MUSCLES *†

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It is well known that the larynx is employed in numerous ways, and that numerous factors are involved in its neurogenic controls The behavior of the intrinsic laryngeal muscles under various functions must be dependent upon the central mechanism, of which, however, little is known If the centers causing the laryngeal movements were different it is probable that a different pattern of activity would take place This study was undertaken to differentiate the motor pattern displayed in the laryngeal muscles under various actions by recording the discharge of the individual motor unit

In the present experiments only the respiratory activity is considered The respiratory movements of the vocal cords in man were investigated by Pressman,[10] by recording a slow motion picture He showed that basically the glottis widened during inspiration and narrowed during expiration These movements are so slight in certain persons during quiet respiration as to be almost imperceptible, while, in dyspneic breathing, they increase in excursion so that the lateral movement of the cords during inspiration becomes progressively wider as inspiration becomes deeper and more forceful By recording the smoked drum tracings, Negus[9] showed that the widening of the glottis preceded a contraction of the diaphragm, and narrowing occurred just before the beginning of

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expiration Recently an investigation on impulse activity of the recurrent nerve and electromyographic recording of activity in the intrinsic laryngeal muscles was reported by Green and Neil,[8] showing that the abductor muscles fired during inspiration, while the adductors showed an activity during expiration, and that the inflation of the lungs abolished the activity in the abductor and excited the discharge in the adductors

As these muscles were relatively inaccessible to the electromyographic examination in a human subject, it was decided to explore the movements which take place in anesthetized experimental animals

### METHOD

Dogs were used throughout the experiments, anesthetized with intravenous sodium pentobarbitone, about 30 mg/kg body weight The neck was opened at the mid-line, and the larynx was exposed, carefully avoiding injury to nerves and blood vessels Access to the muscles was obtained by direct visual controls Sometimes the trachea was cut at the lower margin of the larynx, in such cases the animals no longer breathed through the larynx In order to produce dyspnea, animals were connected to a rebreathing bag, allowing them to rebreathe a limited volume of oxygen and to accumulate carbon dioxide

Electromyographic recording was made by inserting a concentric needle electrode The needle electrode led to a cathode ray oscillograph and loud speaker via a resistance capacity coupled amplifier The action potentials were recorded by using a magnetic type oscillograph on a sheet of moving bromide paper on which the pneumograph was recorded simultaneously

As the needle electrode of this type is not sufficiently selective to give information on the pattern of a single motor discharge, special care was taken to avoid an intermingling of the activities of other adjacent units, because, if more than three or four units were active it would be difficult to interpret the electrical records

## RESULTS

The electrical activity in five intrinsic laryngeal muscles was examined The thyro-arytenoid, crico-arytenoid lateralis and interarytenoid are the adductor muscles which cause approximation of the vocal cords with consequent narrowing of the glottis The crico-thyroid is believed to regulate the length or tension in the cords, and to complete the degree of adduction On the other hand, the crico-arytenoid posterior abducts the arytenoid cartilage and widens the glottis

When the needle electrode was inserted into the muscle, it was found that the adductors, except the thyro-arytenoid, which remained quiet throughout the whole respiratory cycle, showed activity during expiration, while the abductor was active during inspiration The features of motor neuron discharge which were recorded from the intrinsic laryngeal muscles during respiration, were similar to those described by Adrin and Bronk,[2] Bronk and Ferguson,[3] and Gesell, Magee and Bricker[6-7] for the phrenic and intercostal neurons, that is, during quiet breathing only a fraction of the motor units was active, and the activity in most of these consisted of a short train of impulses The records exhibiting a characteristic pattern are illustrated herewith (see Fig 1) Discharge frequencies of a single unit operating phasically were between five and 50 impulses/sec In the adductors the frequency of impulses was the greatest at the start of expiration and gradually dropped away as expiration proceeded, and ceased at the end of expiration On the other hand, in the abductor muscles the frequency was low at the start of inspiration and rose gradually as inspiration proceeded, *i e*, the intervals between successive impulses became progressively shorter Its increasing rate of discharge reached a peak at the end of inspiration, where the firing abruptly ceased at or before expiration

Although the majority of the motor units fired phasically, some units (see Fig 2) showed a continuous train of impulses whose frequency rose and fell with the respiratory cycle, as if the steady continuous frequency was modulated by the rhythm of breathing These units fired continuously expiration Recently an investigation on impulse activity of the recurrent nerve and electromyographic recording of activity in the intrinsic laryngeal muscles was reported by Green and Neil,[8] showing that the abductor muscles fired during inspiration, while the adductors showed an activity during expiration, and that the inflation of the lungs abolished the activity in the abductor and excited the discharge in the adductors

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Electromyographic recording was made by inserting a concentric needle electrode The needle electrode led to a cathode ray oscillograph and loud speaker via a resistance capacity coupled amplifier The action potentials were recorded by using a magnetic type oscillograph on a sheet of moving bromide paper on which the pneumograph was recorded simultaneously

As the needle electrode of this type is not sufficiently selective to give information on the pattern of a single motor discharge, special care was taken to avoid an intermingling of the activities of other adjacent units, because, if more than three or four units were active it would be difficult to interpret the electrical records

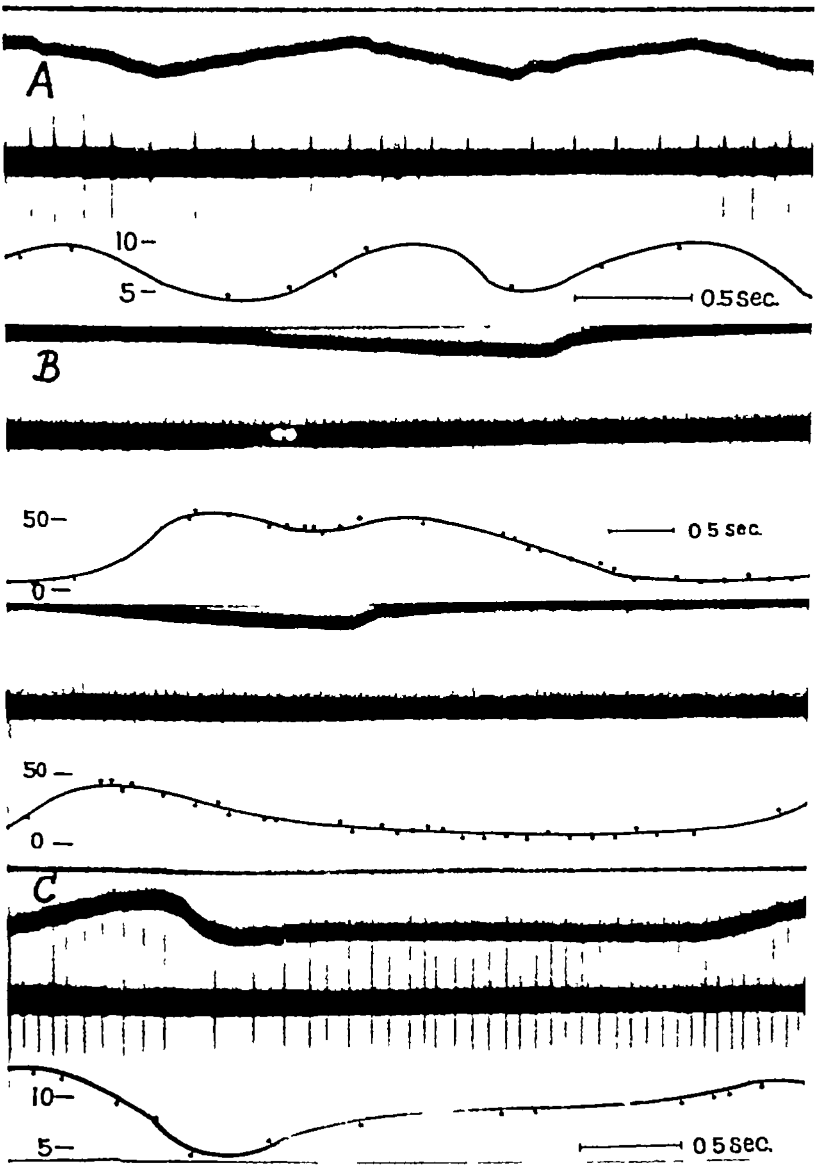


Fig 2 Continuously discharging unit recorded from the adductors (A) (B) and abductor (C) These units fired continuously throughout inspiration and expiration but in adductors increasing in rate during expiration and in abductor increasing in rate during inspiration Upper line is pneumogram upwards movement indicating inspiration Lower line is graph of impulse frequency

throughout inspiration and expiration the abductor increasing in frequency during inspiration, while the adductors increased in rate during expiration Many of the continuously discharging units fired at rather slow rate, namely, they increased their frequency from the range of 5-10 impulses/sec during rest, to the range of 10-20 impulses/sec during contraction, however, sometimes a considerably high rate was observed, 50-60 impulses/sec (see Fig 2-B)

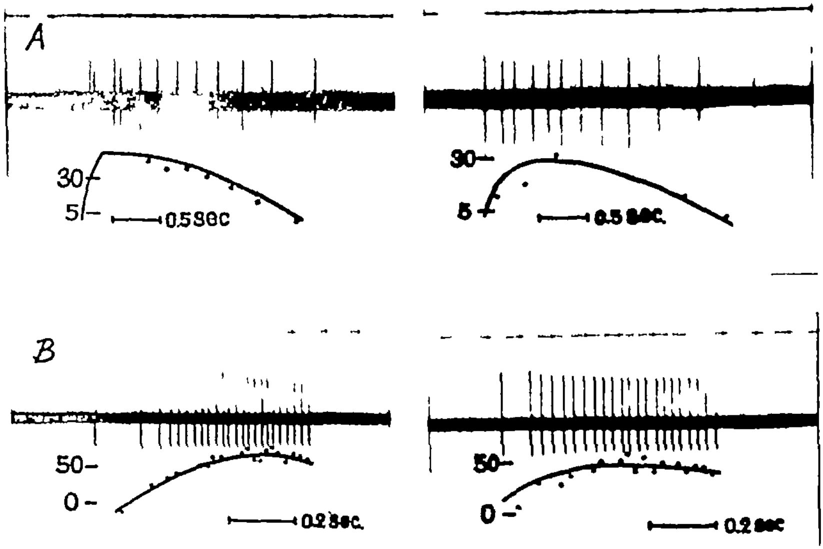


Fig 1 Electromyogram recorded from crico-arytenoideus laterals (A) and crico-arytenoideus posterior (B) The adductor shows decelerating activity, while the abductor exhibits a characteristic accelerating pattern Lower line is graph of impulse frequency

It may be assumed that functionally the motor units in laryngeal muscles fall into two groups The members of the first group perform a phasic contraction during respiration and those of the second group serve to maintain the muscle tone underlying the phasic movements

When respiration was stimulated by causing animals to rebreathe a limited volume of air the frequency of discharge

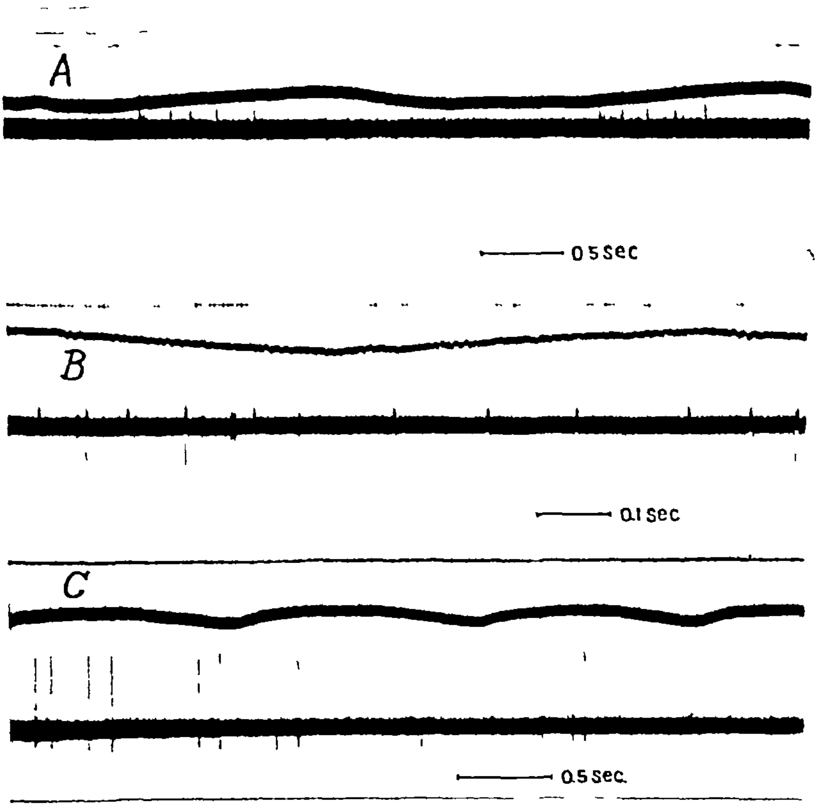


Fig 4 Electromyogram recorded from crico-thyroideus (A) continuously discharging unit of crico-thyroideus (B) and of crico-arytenoideus posterior (C) showing the effects of anesthesia on respiratory activity The impulse frequency decreased and intervals of each successive impulse become more or less at random Upper line pneumogram (expiration down)

fibers discharging impulses decreased so that the number firing in a train became fewer The pattern of discharge lost its characteristic nature, and intervals of each impulse became more or less at random

In order to eliminate the influence of air current on the muscle movements, the trachea was sectioned at the lower end of the larynx No appreciable change in activity was observed, even when air was artificially blown into or sucked through the larynx asynchronously with the respiratory rhythm When dyspnea was produced, an increase in activity

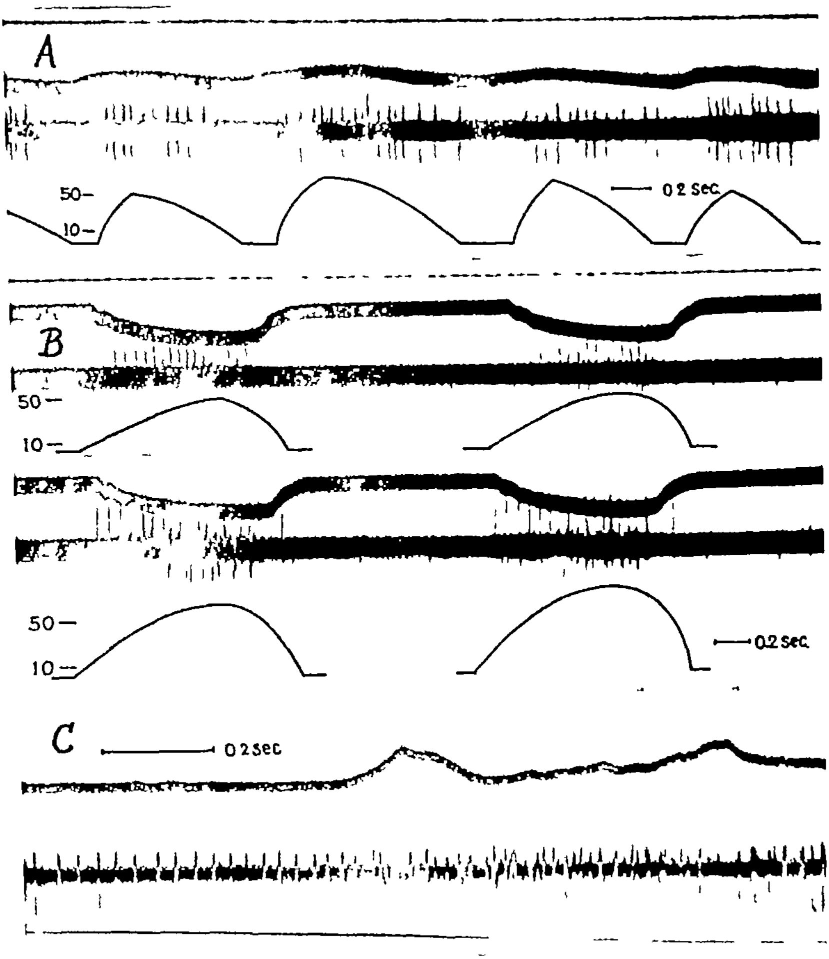
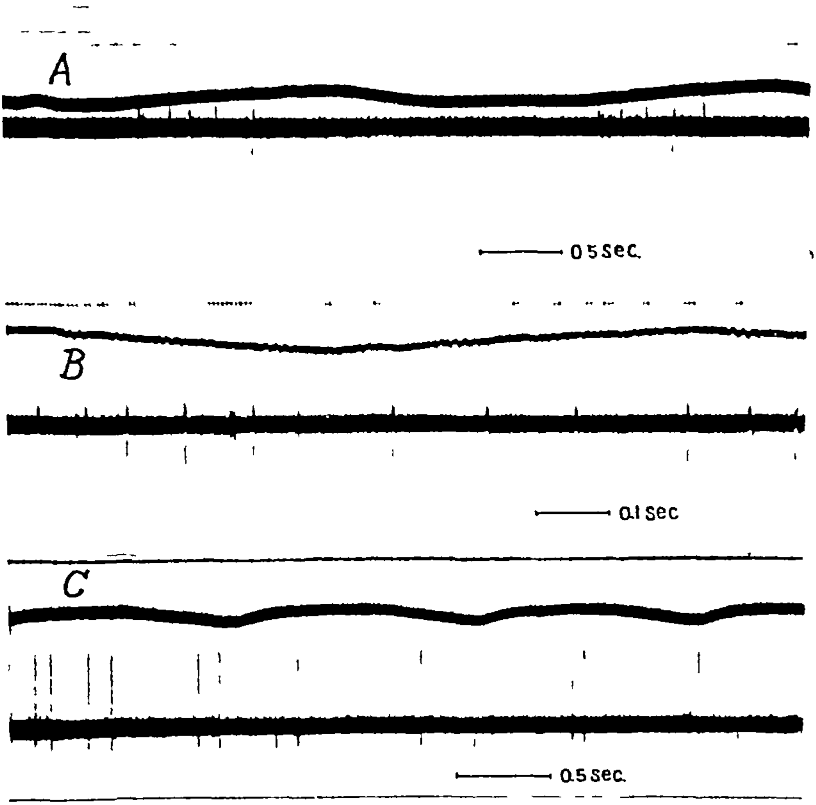


Fig 3 Electromyogram recorded from crico-arytenoideus lateralis (A) crico-arytenoideus posterior (B) and continuously firing unit in crico-thyroideus (C) during dyspnea The frequency of firing increased and other unit discharging impulses were recruited Upper line is pneumogram (expiration down) and lower line is graph of impulse frequency

and the train of impulses increased, and additional motor units which discharge impulses, were added or recruited (see Fig 3) Continuously firing units also increased in their frequency as respiratory movements became more violent

Effects of anesthesia are illustrated in Fig 4 In such a case the frequency of impulses and the number of active



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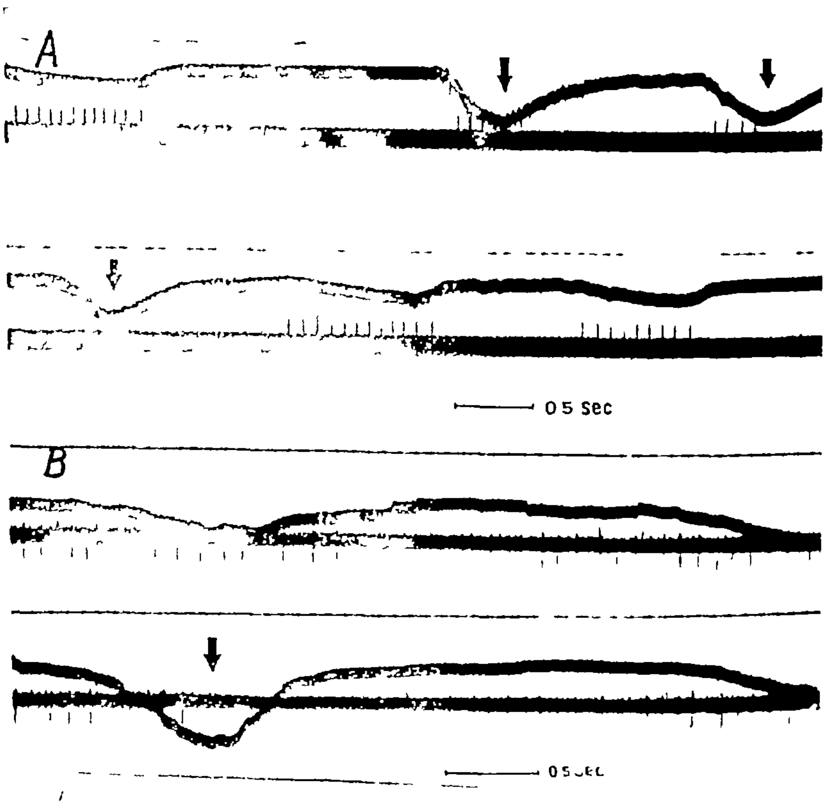


Fig 5 Effect of inflation of lungs upon a phasically operating unit (A) and a continuously discharging unit (B) Arrows indicate inflation Diminishing and abolishing of activity after inflation is obvious Upper line is pneumogram

invariably took place, regardless of an air flow through the larynx It seemed that the laryngeal respiratory movements were not affected by local sensory information evoked by the force of air current

The abolition of phasic activity in adductor muscles caused by inflation of lungs, reported by Green and Neil,[8] was also confirmed (see Fig 5-A) Fig 5-B shows the effect of inflation upon continuously discharging units After strong inflation a continuous train of impulses during inspiration became abolished, but, during expiration they fired as usual

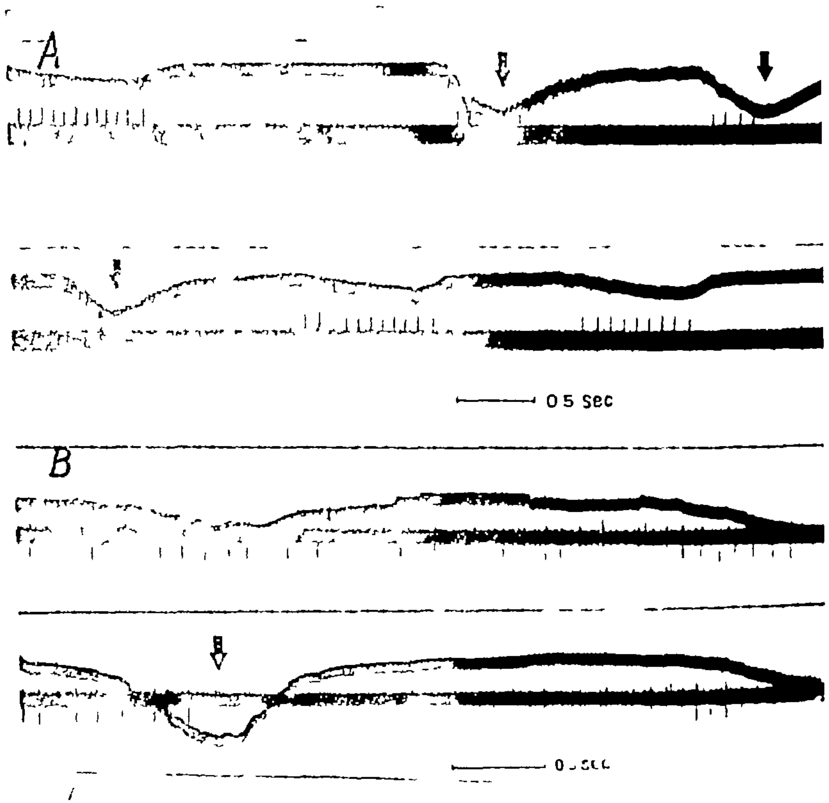
## DISCUSSION

The firing pattern in the adductor muscles of the larynx would be regarded, according to Gesell and others, as a rapidly augmenting type characteristic of the intrinsic expiratory muscles, and that of the abductors as a slowly augmenting type characteristic of the genuine inspiratory muscles In respiratory activity the laryngeal muscles' response is similar to that of the intrinsic respiratory muscles in anesthesia, dyspnea, and the reflex evoked by stretch receptors in the lungs It might, therefore, be concluded that during respiration the motor neurones innervating the laryngeal muscles are influenced by the respiratory centers in a manner similar to those of the genuine respiratory muscles

The intrinsic laryngeal muscles exhibit a basic tonic activity, as suggested by Jackson and Jackson[12] The periodic widening and narrowing of the glottis is superimposed upon this underlying muscle tone The tonic activity in respiratory muscles is said to have a significant role in maintenance of posture, particularly against the force of gravity, but, as in the larynx, the force of gravity acting on the cords might be so slight and negligible that it would not be unreasonable to suppose that movements of the cords would take place around the mid-position which might be determined by the balance between these tetanic contractions in a larger or smaller portion of motor units in the antagonistic muscles

The problem, as discussed by Andrews[13] on the respiratory displacement of the larynx, "How is the balance maintained?" has not yet been explained satisfactorily The continued activity of the laryngeal muscles during respiration after the detachment of the trachea and the great increase in activity when dyspnea was produced, indicate that the position or movements of the cords are not passively determined by the force of air current through the glottis chink

It is said that the laryngeal muscles, as well as the muscles of the tongue, face and middle ear do not contain muscle spindles[11] Fernand and Young[5] have classed the recurrent laryngeal nerve in rabbits as unimodal, containing few or no proprioceptive fibers Campbell and Murtagh,[4] reporting the



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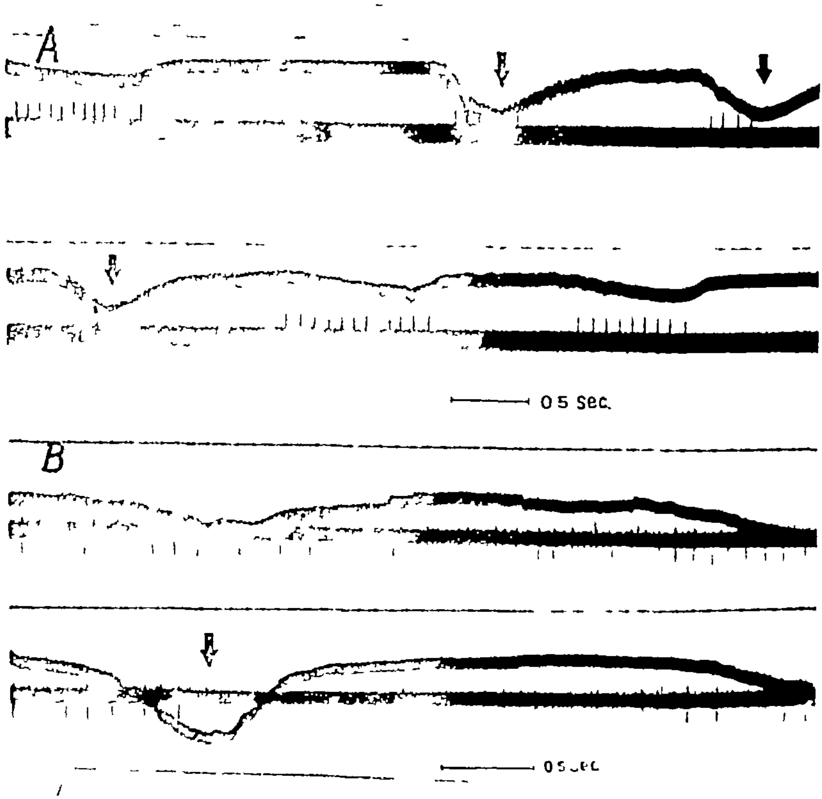

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Regarding the useful results of respiratory movements of the glottis, there is no doubt that the effect of widening at the glottis chink at or just *before* inspiration is a reduction of resistance to an inflow of air. On the other hand, the effect of the constriction, beginning prior to expiration and continuing through it, is suggested by Pressman[16] to have a significance upon the phenomenon of air mixing within the lungs. It is widely known that respiration is shallow and somewhat irregular in case of a laryngectomized patient. This might probably be due to the lack of resistance or, in other words, appropriate "load" to an outflow of air. It might be safe to say that the laryngeal muscles, as well as the muscles of the wings of the nares and bronchi, should be called "the regulatory muscles of the respiratory passage," which serve to regulate the section of the respiratory passage, reducing the resistance to inspired air, and giving it the appropriate load to keep respiration deep and regular.

## SUMMARY

The electrical activity in five intrinsic laryngeal muscles of the dog during respiration was examined with electromyographic recordings. The abductor was active during inspiration, while the adductors showed activity during expiration, except the thyroarytenoideus, which remained quiet throughout the respiratory cycle.

The pattern of activity in the laryngeal muscles showed a close similarity to that of intrinsic respiratory muscles

No change in activity after the detachment of the trachea indicates that respiratory movements of the glottis may be controlled centrally without reference to a local sensory information Effects of respiratory movements upon respiration were discussed

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# NYSTAGMOGRAPH FOR CLINICAL USE *

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and
NICHOLAS TOROK, M D ,‡
Chicago, Ill

The photoelectric nystagmograph presented in this paper is similar in its principle of operation to the instrument described previously by Torok, Guillemin, and Barnothy[1] The equipment described here is, however, much lighter and more compact, and incorporates several improvements that result in greater reliability and in simpler, quicker and more convenient recording of nystagmic eye motions

The entire optical and photoelectric system of the new instrument is mounted upon a headband and goggle frame fitted to the patient Recordings may be made with the patient in any position, seated, in bed or on a revolving chair Preparation of the patient for a recording may be accomplished in a minute or two so that the whole process of making a record, either by thermic stimulation or by means of the rotating chair, requires little more time than the usual clinical procedure of visual observation of nystagmus

The advantages of graphical recording are obvious A graphical record shows many details that are not obtainable by direct observation, and an analysis of the graph provides data on the duration, frequency, change of frequency, amplitude and form of the nystagmus, that are valuable both in clinical practice and in vestibular research[2 3]

Most of the recordings of nystagmus make use of the corneo-retinal potential difference picked up by electrodes placed at various positions in the immediate vicinity of the

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eye The usefulness of this method is clearly demonstrated in the recent work of Aschan et al [4], who obtained very reliable and instructive nystagmographs in serial clinical investigations We cannot agree, however, with the statement of these authors that the photoelectric method has been superseded by the method of potential pick-up On the contrary, our experience in the laboratory and in the clinic shows that our photoelectric method gives excellent records and is most practicable in terms of convenience and economy of time required to obtain a record

As previously described, the instrument makes use of the difference in reflection of infrared light from the dark iris and the light sclera of the eye A focused beam of infrared light forms an illuminated area on the eyeball approximately 1 mm wide by 16 mm long, so situated that it lies partly on the iris and partly on the sclera as shown in Fig 1-A This position is appropriate for the observation of horizontal nystagmus To record vertical motions, the light beam is oriented as shown in Fig 1-B The light beam is fixed relative to the patient's head, therefore, any motion of the eyeball will vary the portion of the beam striking the sclera Since the sclera has a higher reflectivity for infrared, as compared to the iris, the total amount of light reflected from the eyeball will change with every movement of the eye This reflected light falls upon a photocell, located close to the eyeball, and

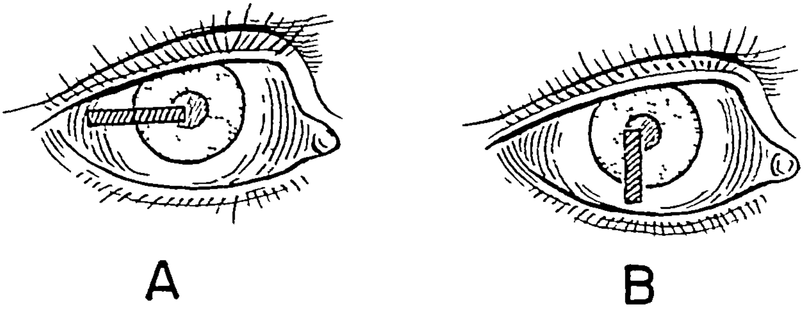

Fig 1

is converted to corresponding changes of electrical potential that are electronically amplified and recorded

Fig 2 shows a schematic diagram of the complete optical and electronic equipment arranged for recording nystagmus on the revolving chair The same equipment is used when thermic stimulation is employed, except that the connections through rotating slip rings and stationary bruches are unnecessary

Immediately in front of the eye, which is illuminated as described, are a pair of photocells These are Bell laboratory photovoltaic cells (sun batteries) in the form of small flat rectangular plates, 5 mm by 20 mm They are connected electrically in series so that their output is additive, that is, they function as a single cell

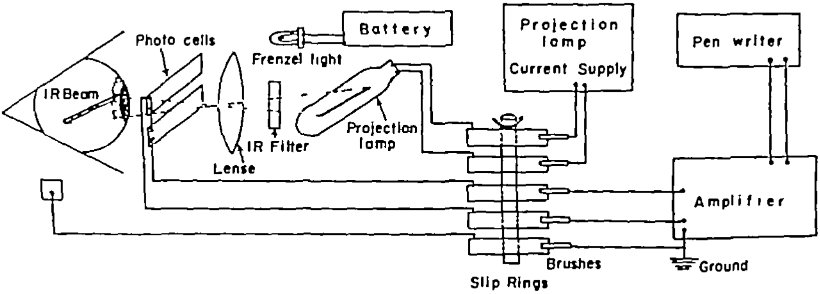

Fig 2

The light source is a special projection lamp having a single straight filament that acts directly as a source of illumination A short focus projection lense focuses an image of this filament upon the eyeball A glass infrared filter is interposed in the light beam to absorb the visible light of the lamp This prevents visual stimulation of the eye during the recording of nystagmus The filter is mounted in a sliding holder so that it may be moved out of the path of the beam for visual focusing and positioning of the image on the eyeball

A 20-diopter lense is mounted directly before the opposite eye to be used for visual observation when desired, in the manner of the Frenzel glass A small electric lamp, located behind this lense, gets its current supply from a portable dry cell battery This lamp is well shielded and operates at low intensity, just sufficient to permit visual observation of the eye in a darkened room

All the parts described thus far, with the exception of the dry cell battery, are mounted on a headband and goggle frame fitted to the patient's head

Electrical connections from the photocells on the revolving chair to the stationary electronic amplifier are made via the usual slip rings, revolving with the chair, and stationary brushes bearing on these rings Two similar connections are used for the electric current supply of the projection lamp This is provided by a well-filtered low-voltage direct current source that is operated on the 115 volt, 60 cycle power lines It is essential to operate the projection lamp on steady direct current, since the photoelectric system is fast enough to respond to the 120 cycle per second light intensity fluctuations of a lamp operating on alternating current This direct current source is controlled by a switch having a "low" intensity position, used while focusing the beam on the eye, and a "high" position used when the infrared filter is moved into the light beam

The amplifier is of the a c type with a flat frequency response over the range of one-half to 200 cycles per second This range is adequate for recording practically all types of nystagmus, both spontaneous and induced, without appreciable distortion The amplifier is provided with an electronic limiter that prevents excessive output signals due to blinking or large voluntary eye movements The amplifier actuates a commercial pen recorder having a frequency response range of zero to approximately 100 cycles per second The recorder thus limits the overall upper frequency response of the equipment

The actual construction of the headband, goggle frame and optical equipment, is shown in Fig 3, which shows both a front and back view The housing for the projection lamp,

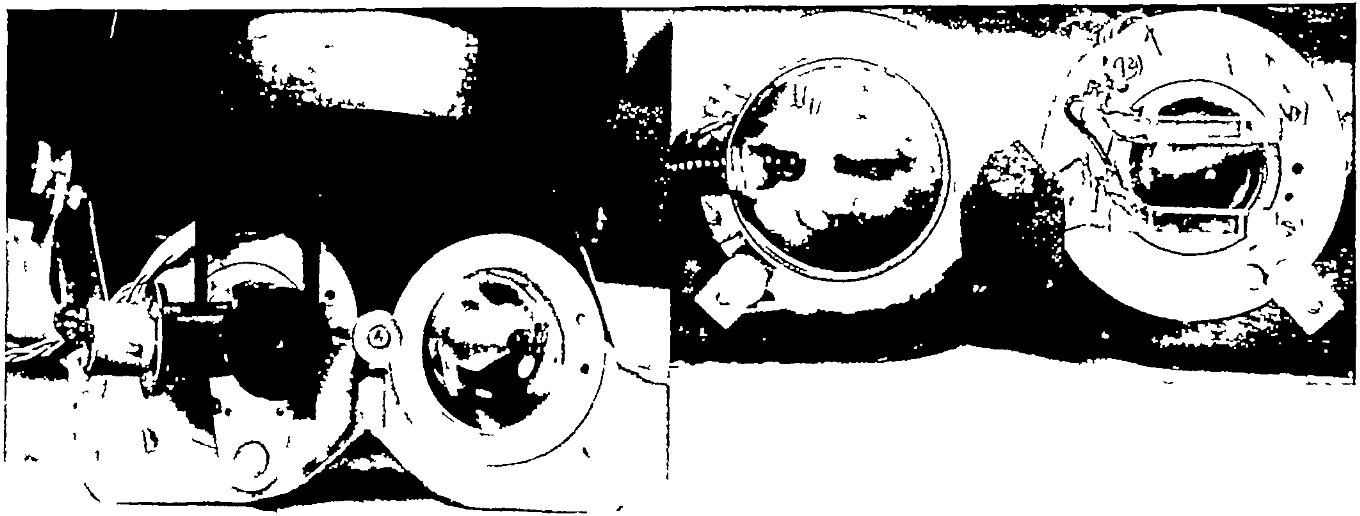

Fig 3

lense and infrared filter in its retractable slide is shown to the left of the front view. This whole assembly is mounted as a unit, in a sliding and rotating ball-and-socket joint that permits axial motion for focusing and also angular rotation. In addition, the optical assembly may be tilted in all directions for adjusting the beam to its proper position on the eyeball. All these adjustments are fixed by tightening a single thumb nut. Further adjustments are provided for headband size and nose configuration.

The Frenzel glass, together with its small illuminating lamp, is mounted on the opposite side of the goggle frame, and both the Frenzel glass and the optical assembly are mounted upon circular metal discs that fit into semicircular openings in the goggle frame. They are held in place by thumb screws and are easily removable from the goggle frame so that their positions may be interchanged, that is, the light beam may be positioned on the right eye with the Frenzel glass before the left eye, or vice versa.

The rear view of the goggle frame shows the projection lense with the two photocells before it, and the small lamp of the Frenzel glass. Fig. 4 shows the apparatus fitted to the patient's head.

The two photocells, as stated above, act as one. Actually, one cell would suffice, however, because of the great variation of head and nose sizes and shapes, the light beam may fall upon the eyeball in a slightly upward or downward slanting direction with various patients so that the reflected beam is directed respectively, somewhat downward or upward. In either case, one or the other of the two cells will be well illuminated by the reflected light. Thus, with two cells, the adjustment of the beam is less critical, and may be accomplished quicker and more easily.

The rotating chair (see Fig. 5), used with the above equipment, was assembled at low cost and is adequate for routine clinical tests. It has an electrical variable speed drive giving a range of angular velocities of the chair from 2.5 to 90 degrees per second (0.42 to 15 turns per minute) in either direction of rotation. There is no adjustment for angular acceleration or deceleration The chair reaches full angular velocity, upon starting, in about two seconds, and is stopped by a hand brake in less than one second

Calibration of the equipment, in millimeters of pen excursion per degree of eye deflection, is accomplished by means of a simple perimeter (see Fig 5), having two small neon

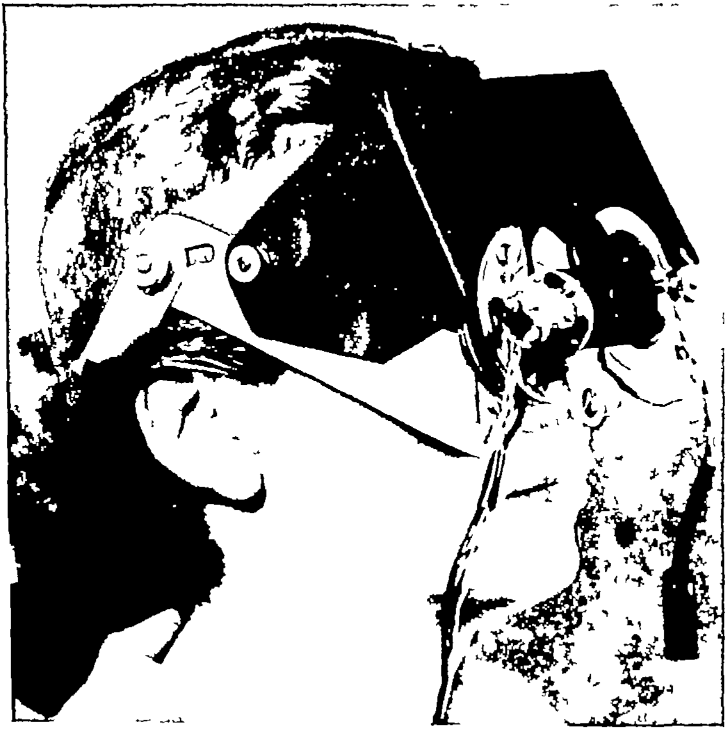

Fig 4

lamps that may be positioned at various angular separations as measured at the patient's eye, from 5 to 30 degrees of arc A hand switch shifts the illumination quickly from one lamp to the other, and the patient is instructed to follow the light with his eyes while keeping his head at rest

The whole equipment is inherently linear in response to well within its limit of precision, which is about 0 2 mm for visual measurement of the pen record This degree of lineainty is found in the output of the photocell, in the response of the amplifier, and in the excursion of the pen recorder, however, when carrying out a calibration on a given patient there is a large factor of uncertainty, depending upon the precision with which he can follow the apparent motion of the light on the perimeter A trained and cooperative subject can repeat successive eye movement for the same perimeter setting within about 2 per cent, but an untrained or uncooperative patient may vary his eye motion as much as 10 or 20 per cent at the same setting In such cases only a very rough calibration can be accomplished

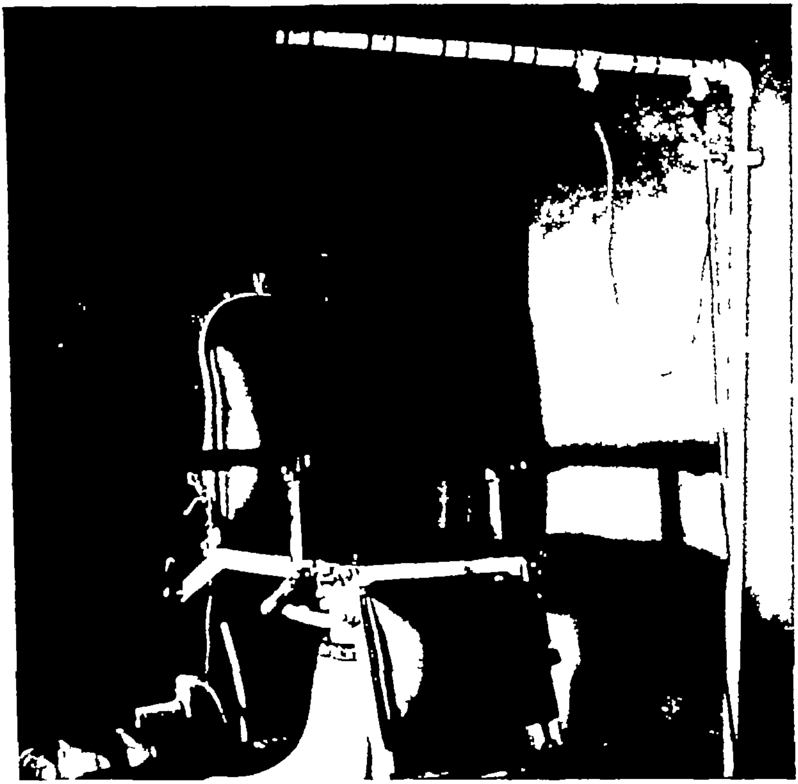

Fig 5

The overall sensitivity is ample for all recordings A motion amplification of twenty to one is obtained readily, that is, a linear motion of 0 5 mm at the surface of the eye may produce a pen excursion of 10 mm Thus it is possible to record nystagmic motions so minute that they would not be noted by visual observation of the eye

Photoelectric recordings of nystagmus has been described and used successfully by Pfaltz and Richter[5] The principle of operation of their apparatus is, however, somewhat different They illuminate the entire area of the iris plus the near adjacent areas of the sclera on both sides of the iris Two photocells, positioned laterally and connected in opposition, so that their output potentials are opposed, record the simultaneous and opposite changes of illumination on both sides of the iris when the eye moves

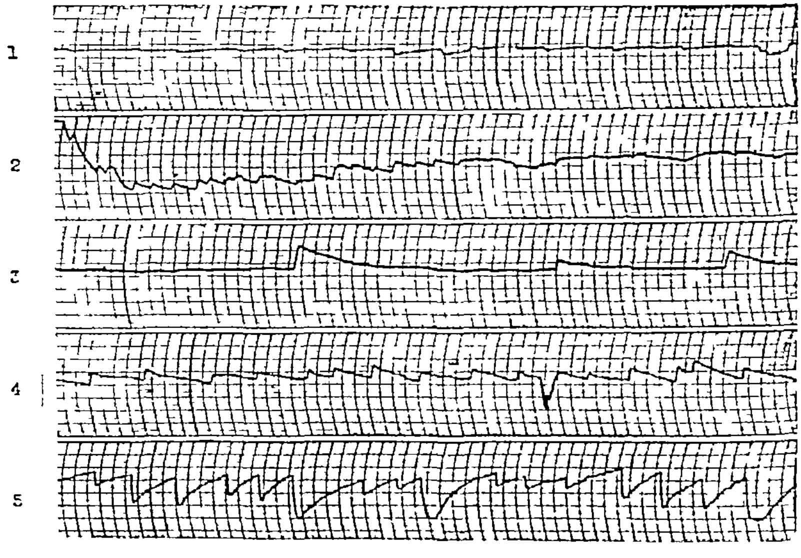

Fig 6 Nystagmograms of Various Types Five horizontal bars represent 1 sec time 1 Spontaneous nystagmus small amplitude constant frequency 2 Postrotatory nystagmus obtained through the electrically driven chair 45 /sec velocity and sudden stop total duration within normal limits nystagmus frequency elevated 3 Postrotatory nystagmus obtained under identical conditions as graph No 2 total duration normal very low frequency but larger amplitude 4 Thermic nystagmus obtained by 10 cc 68 of water even amplitude normal frequency the one irregular excursion downward is the result of a blinking of the eyelids 5 Thermic nystagmus 10 cc 68° water larger and uneven amplitudes frequency within average normal limit

With the use of a focused light beam as described here, only one iris-sclera boundary is illuminated It is thus possible to make recordings of first degree nystagmus where the eye is deflected so far to the side that one edge of the iris is occluded by the eyelids When both second and first degree nystagmus is to be recorded in succession, the beam may be so positioned that one or the other edge of the iris lies well within the beam both in the forward and the sideways deflected position of the eye

The photoelectric study of nystagmus requires that the eye be held open during the actual time of recording This does not appear to have any effect upon the nystagmic response when the patient is in a darkened or dimly lighted room The opened eye is, of course, required in any case where the recording is to be checked by simultaneous observation through the Frenzel glass Actually this means of observation was provided in the present apparatus primarily to check its operation during the development and testing period The recorder has proven so reliable that visual observation is seldom used in routine clinical tests

Fig 6 shows several typical records obtained with the photoelectric nystagmograph

## SUMMARY

This paper describes a photoelectric nystagmograph, using invisible infrared light, suitable for recording all types of nystagmic eye motions, except pure rotatory nystagmus It is particularly well adapted for routine clinical tests with thermic or rotatory stimulation, but is also suitable for physiological research It provides very reliable records that show all the details of form, amplitude, frequency and duration of the vestibular reaction

The apparatus comprises a headband and goggle frame, fitted to the patient's head, upon which the optical and photoelectric equipment is mounted This is connected to an electronic amplifier and pen recorder that supplies an immediate pen record of the nystagmus

The recording is conducted in a dimly lighted room The

motions of one eye supply the infrared light signals for the recorder The other may be observed simultaneously, if desired, through a 20-diopter lense in the Frenzel method

By a simple operation the optical assembly and the Frenzel glass may be interchanged so that either eye may be used to supply the record

In clinical use, recordings may be made in only a few more minutes of time, and with no more discomfort to the patient than in the usual procedure of visual observation of nystagmus

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## SHAMBAUGH PRIZE—COLLEGIUM O R L A S

Dr Glen E Wever, of Princeton, was recently awarded the Shambaugh prize which is presented every second year by the Collegium Otorhinolaryngologicum Amicitae Sacrum, for outstanding work on the physiology of the auditory organ

# EUSTACHIAN TUBE BIOPSY CANNULA

MAHMOUD K MUFTIC, M D ,*

Basrah, Iraq

Tubal obstruction usually affects the nasopharynx in various ways ranging from acute and chronic inflammation of the adenoids to benign neoplasm and hypertrophy of the nasopharyngeal tissues

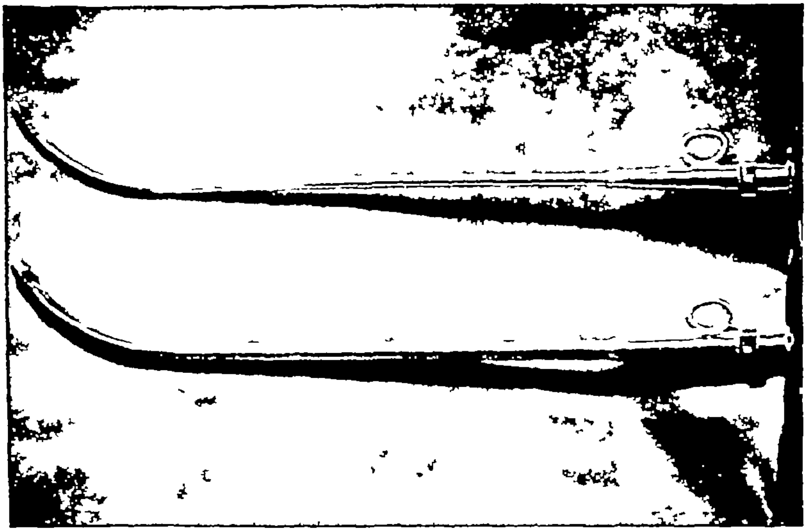

Fig 1 Muftic s Biopsy Cannula for Eustachian Tube

The usual procedures for investigating the cause of tubal closure, posterior rhinoscopy, nasopharyngoscopy, tubal insufflation, etc , were not productive of proper analysis in the case in question, consequently it was necessary to establish a simple routine procedure which would permit biopsy from the tubal orifice and from Rosenmuller's fossae, thus giving a histopathological diagnosis of the obstruction

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To simplify the technique, an instrument† for obtaining specimens for biopsy was designed in the shape of a Eustachian tube catheter adaptable to a B-D syringe (LL) The end piece may be of two different types resembling the endometrial cannula-curette according to Raydal and Novak, but of a smaller size

This cannula-curette is introduced by the same technique as in ordinary catheterization of the Eustachian tube The catheter is introduced (with or without local anesthesia), and when it is engaged in the tubal orifice or well in Rosenmuller's fossa, strong suction is applied by aspirating the syringe or adapting cannula to a suction unit After complete suction, the cannula is withdrawn and the tissue is removed from the cannula by strong insufflation, and placed in the proper fixing solution

The stain for the small biopsy is made according to Papanicolaou, and thicker pieces are embedded for histopathological investigation by the usual staining techniques

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†These instruments are made from my design by Down Bros and Mayer and Phelps 92 Borough High Street London S E 1 to whom I am most grateful

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## AMERICAN SOCIETY OF FACIAL PLASTIC SURGERY

The Annual Spring Meeting of the American Society of Facial Plastic Surgery will be held March 10-11, 1958, at Columbus, Ohio For further details write Dr Samuel M Bloom, Secretary, 123 East 83rd Street, New York (28), N Y

# ANESTHESIA METHODS FOR BRONCHOSCOPY AND THEIR USEFULNESS IN PRACTICE*

E J KNUDSEN, M D ,
H RASMUSSEN, M D ,
H RUBEN, M D ,
and
P TRAUN-PEDERSEN, M D ,
Copenhagen, Denmark

Bronchoscopy, when introduced into clinical practice about the turn of the Century, was employed chiefly for removal of foreign bodies In the course of years, the use of diagnostic bronchoscopy has steadily increased

Bronchoscopy, carried out in deficient anesthesia, is an extremely disagreeable experience to the patient, moreover, the diagnostic value of bronchoscopy in a patient offering resistance is doubtful, and finally, bronchoscopy under such circumstances involves a risk of injury

Endeavors have, therefore, been made to find a satisfactory method of anesthesia, but the multiplicity of proposals proves the difficulty of the task The main troubles are that the anesthetist and the surgeon work in the same field and, therefore, easily get in each other's way, and that the field concerned is sensitive with very brisk reflexes

Formerly, the choice lay between local and general anesthesia, the latter in the form of inhalation anesthesia Within recent years a number of methods, new in principle, have been introduced We have found it appropriate to try some of these in practice and attempt to assess their usefulness

The demands to be made on an ideal method are the following

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*From the Finsen Institute Copenhagen Anesthesiology Department (Head H. Ruben M.D ) and E N T Department (Head H Rasmussen M.D )

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*1* A minimum of risk to the patient

*2* Removal of discomfort to the patient

*3* Undisturbed working conditions for the surgeon

*4* Simplicity of technique and apparatus

*5* A short restoration period (of particular importance in cases of out-patients)

Local anesthesia, with or without premedication, was previously the most frequently employed method for adults, and is still used in some cases With reference to the above-mentioned demands, it is seen that

*1* The method, on the assumption of adequate dosage, fulfills the requirement of safety

*2* In few cases only does it remove the discomfort to the patient

*3* It rarely renders possible undisturbed examination In cases of nervous patients it is impossible to carry through bronchoscopy in local anesthesia alone

*4* The technique is simple

*5* It is suitable for out-patients

In cases unfit for local anesthesia inhalation anesthesia was previously the only other possibility Examination then had to be performed during the restoration period, after the dosage had been stopped The examination requires deep anesthesia The degree of the consequent depressed respiration and a possible cyanosis are difficult to follow during endoscopy in a dark room The anesthetist will often have to intervene while the surgeon is at work, either to ventilate with oxygen or to add a supplementary amount of ether, for instance In case of difficulty with the introduction of the bronchoscope, a laryngeal spasm may occur, which will often start a series of unpleasant complications Regarding the above-mentioned demands we have found that

*1* The method is not without risk

2 The discomfort of bronchoscopy is replaced by discomfort of anesthesia

3 The surgeon cannot work undisturbed

4 The technique certainly is simple, but it is difficult to manage in practice

5 The restoration period is fairly long, and the method, therefore, is unfit for out-patients

The only cases where inhalation anesthesia may be indicated are those of bronchoscopy in children, where the modern forms of general anesthesia may be difficult to administer In cases of children with obstructing or potentially obstructing foreign bodies in the air passages any kind of general anesthesia must be regarded as contra-indicated Non-obstructive foreign bodies in the air passages of children can often be removed in vinyl ether-and-ether anesthesia, but an excellent method has been indicated by Toker, using thiopental-sodium and succinyl-choline-iodide, and cuirass respirator *(vide infra)*

## MODERN ANESTHETIC METHODS

*A* Local anesthesia suplemented by general analgesia, obtained with pethidine intravenously

*B* General anesthesia obtained with barbiturates supplemented by short-acting relaxants

### *A Local Anesthesia Supplemented by Pethidine Medication*

A previous investigation showed that endoscopy through the pharynx, including bronchoscopy, could be greatly facilitated by injecting pethidine intravenously, due partly to the depressing effect of pethidine on the laryngeal and pharyngeal reflexes, and partly to the mentally relaxing and pain-stilling action of pethidine in the doses used, an action which may be characterized as one of general analgesia Not infrequently there is found amnesia with regard to discomfort of the examination

The method has now been employed for bronchoscopy in more than 400 cases at the Finsen Institute during the past six years, with an exceedingly favorable result With reference to the previously mentioned demands we have found that

*1* The risk involved must be supposedly less than that of local anesthesia alone, as the amount of anesthetic, if pethidine is used, can be reduced Oximetry shows that the reduction of the oxygen saturation in cases with pethidine medication is slight, being of the same order as at bronchoscopy in local anesthesia alone, where a reduction occurs when the bronchoscope causes obstruction, *e g ,* when it is introduced into one of the bronchi This can possibly be explained by the way in which the depressing effect of pethidine on the respiration is abolished by the stimulating effect of the intervention itself

*2* Pethidine greatly reduces the discomfort to the patient Reactions in the form of nausea are rare, the skin occasionally becomes pale and slightly moist, but the blood pressure does not fall, and there is seen only the minor rise in pulse rate which corresponds to the parasympathicolytic action of pethidine Liberation of histamine with transitory redness along the course of the vein has been seen in a few instances, but no bronchospasms or collapse

*3* By employing local anesthesia it has, in the great majority of cases, been possible to carry through undisturbed and thorough bronchoscopy, most often including the taking of biopsy specimens and use of the telescope

*4* The method is simple and, if necessary, can be practiced by the surgeon alone, aided only by a nurse to watch the patient during and after the operation

*5* The method is suitable for out-patients, the majority of whom can resume their daily work after a few hours' rest After removal of the bronchoscope the cough reflexes will suffice to bring up any blood or mucus

*Technique*

We used between 50 and 200 mg (on an average about 100 mg ) pethidine in a 1 per cent solution A good technique of local anesthesia is required to obtain a favorable result

After careful spraying of the mouth and throat, 8 to 10 ml of one-half per cent pontocaine with adrenaline 1 200,000 can, with advantage, be injected in between the vocal cords by means of a syringe fitted with a blunt, curved cannula, which can be passed down behind the epiglottis of the sitting patient The cough produced by the application will spread the injected pontocaine in the trachea and bronchi

Intravenous injection of pethidine is thereafter started, up to 50 mg is given within about 30 seconds, and afterwards supplemented according to requirement Maximum response to intravenously injected pethidine is obtained after a few minutes

*B General Anesthesia*

The use of barbiturates combined with relaxants was first described about four years ago, and various modifications of the technique have already been suggested These represent different solutions of the essential problem of oxygenation during the induced apnea

Evaluation of the barbiturate-relaxant method with regard to fulfillment of the stated demands has shown that

*1* The method involves a much greater risk to the patient than local anesthesia plus pethidine method, because it requires a faultless functioning of a rather complicated technical apparatus, as well as an ideal, preferably firmly established cooperation of surgeon and anesthetist

Failure of a link in the procedure, *e g* , a block in the intravenous cannula, leakage or stoppage of the oxygen supply, trouble with the introduction of the bronchoscope, etc , may within a very short time cause complications, which in the dark room may be difficult to recognize and treat sufficiently early Experience will reduce the incidence of such complications, but the risk is always present We have seen no severe complications in our series, but a few times interruption was necessary due to technical difficulties involving a risk of hypoxia

*2* The discomfort to the patient before and during the operation has been eliminated The discomfort following the intervention is probably somewhat greater than after local anesthesia supplemented by pethidine intravenously

*3* The method yields very good conditions of operation, varying with the different modifications, *(vide infra)*

*4* The method requires the assistance of a specialist in anesthesia

*5* The restoration period is sufficiently short to render the method serviceable for out-patients

The various principles of oxygen supply and the techniques employed will be briefly reviewed

*I* Intermittent ventilation has been suggested by Churchill-Davison, among others Premedication with morphine and atropine is given After intravenous injection of 300 to 500 mg thiopental sodium and 60 to 75 mg succinylcholine iodide, hyperventilation is carried out for 30 to 60 seconds, with pure oxygen by means of mask and bag The vocal cords are thereafter sprayed with a local anesthetic (This has been done in all modifications of thiopental and succinylcholine anesthesia for bronchoscopy, because the relaxant effect vanishes prior to the effect of the barbiturate, so that without local anesthesia removal of the bronchoscope will often be followed by violent coughing and laryngeal spasm) The bronchoscope is then introduced, while at the same time the patient is ventilated with oxygen as often as possible, through a cut rubber tracheal catheter, passed so far into the Negus bronchoscope that it fits airtight

Oximetry shows that adequate oxygenation can be maintained in this way Such frequent ventilations in the bronchoscope are very inconvenient to the surgeon, but they can, to a great extent, be done during intervals of examinations, while the surgeon is changing optical instruments, or the like

The method takes a certain account of the $Co_2$ elimination, being, therefore, fit to be used over a fairly long period, providing curacite is constantly added for the purpose of maintaining apnea Supplementary doses of a barbiturate are rarely necessary, when the examination does not extend beyond 15 to 20 minutes

*II The oxygen diffusion method* has been proposed by Barth for bronchoscopy This method starts with ventilation, using oxygen for three to five minutes, without reinhalation of previously exhaled air (one-way-valve), whereby the nitrogen of the pulmonary air is replaced by oxygen Thereafter the barbiturate and relaxant are given, until complete apnea has occurred, which is maintained throughout the intervention During the bronchoscopy pure oxygen is conducted through a lateral tube in the bronchoscope with side holes

We found that, using this method, a constant maintenance of apnea is necessary, because otherwise the oxygen in the lungs will be "diluted" again with nitrogen, and the oxygen diffusion to the blood thus be reduced

Oximetry showed satisfactory values, providing the above requirements are met As, however, no $Co_2$ is eliminated by this procedure, apnea lasting more than 15 minutes involves a risk of $Co_2$ intoxication, cf Barth's own statement after $pCo_2$ measurements

*III The insufflation method* has been mentioned by Cheatle and Chambers, and others After administration of barbiturate and relaxant, the patient's lungs are ventilated two or three times with pure oxygen The bronchoscope is then introduced, and about one liter of oxygen per minute is conducted through a thin catheter passed down to the carina

The method was found suitable for very short examinations only (Cheatle and Chambers themselves stated five, or ten minutes at most), because the oxygenation is not reliably effective, and $Co_2$ is accumulated

*IV The cuirass respirator method* has been indicated by Toker, and Green and Coleman After administration of a barbiturate, a previously fitted respirator cuirass is placed on the patient's thorax and abdomen, and one makes sure that the respirator functions to satisfaction Then a relaxant is given, and it is controlled so that the respirator takes over the patient's respiration in a satisfactory way If so, the anesthesia can be continued as long as is desirable, affording ideal and undisturbed working conditions for the surgeon

In stocky, fat patients, as well as in patients with a stiff emphysematous thorax, it has been found difficult and in some cases impossible, to obtain sufficient change of air by this method

The apparatus being large and expensive, the method is usually employed in special wards

V *The ventilation bronchoscope* has been constructed by Mundnich and Hoflehner, and its use has been described by Kjaer, among others It is a Negus bronchoscope, provided with side holes at the distal end, so that both lungs are ventilated, even with the bronchoscope passed down into one bronchus The upper end can be closed by a glass pane Through a side inlet close to the upper end of the bronchoscope the patient can be ventilated with gases from an ordinary anesthesia machine

The patient's lungs can thus be ventilated through the bronchoscope during the whole period of bronchoscopy If airtight closing round the bronchoscope is desired, this can be obtained by manual pressing of the soft tissue above the larynx against the bronchoscope During prolonged bronchoscopy it is an advantage to be able to ventilate with a nitrogen oxide mixture, for instance, which allows reduction of the theopental sodium amount used and insures the patient's remaining asleep

When a telescope is used, the glass pane can be replaced by a rubber diaphragm, through which the telescope can be passed airtight Biopsy specimens cannot be taken simultaneously with the ventilation, but can be taken during a pause in this, especially if the patient has been hyperventilated in advance

The method is suitable for bronchoscopies where prolonged and undisturbed examination is desired, *e g*, in the teaching of diagnostic bronchoscopy, but it is unsuitable for bronchoscopies for the purpose of taking biopsy specimens

## CONCLUSION

The practical result of our investigations, in connection with testing of the various methods, is that we still prefer local anesthesia supplemented by pethidine medication as standard method, especially in cases of old and very sick patients, where this method is supposed to involve the least risk A few patients with very brisk reflexes, or very nervous patients, in whom it has been found impossible to introduce the bronchoscope after local anesthesia plus pethidene, we prefer to anesthetize with barbiturate and relaxant, and use ventilation bronchoscope or, when biopsy has to be made, the cuirass respirator method In cases where anatomical conditions render examination in local anesthesia plus pethidine difficult, *e g*, a short stiff neck, long teeth, or the like, one must, however, be prepared for difficulties, also when employing the method with barbiturate and relaxant

## SUMMARY

Early and modern methods of anesthesia for bronchoscopy have been reviewed, with reference to our experience in their use

Local anesthesia supplemented by pethidine intravenously has been found satisfactory, the method being fairly safe, easy to carry out, and yielding sufficiently good operative conditions in the great majority of patients

General anesthesia, using barbiturates and short-acting relaxants, yield ideal conditions of operation, but has been found to involve a greater risk to the patient

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## CONCLUSION

The practical result of our investigations, in connection with testing of the various methods, is that we still prefer organs, particularly of the tongue *Voice* is produced by vibration of the vocal cords in the larynx In addition to these scientifically correct definitions, indicated as such by different typesetting, Webster explains other usages, including their interchangeable meaning as synonyms

The *voice* is one of the audible functions of the larynx, in particular of the vocal cords It is this act of phonation which makes human speech suitable for audible communication Expressed in the terms of the acoustic engineer, the voice represents the carrier wave In further analogy to the superimposition of the vibrations of speech or music by amplitude or frequency modulation of the radio carrier wave, the acoustic characteristics of the speech sounds or vocal timbers are added to the laryngeal voice by the articulatory movements of the speech organs

Following this technical example, we may compare the disorders of human communication to a disturbance in a radio station If the material to be broadcast is lacking, or if the performers fail for any reason, the diffusion of ideas by language or music will be deficient On the other hand, a failure in the acoustic system of microphones, cables, and amplifiers interferes with the proper modulation of the carrier wave, causing distortion or unintelligibility of singing and speech Finally, when the emitters of the carrier wave break down, no radio signal will be on the air to carry the audio frequencies produced by the performing speakers or singers It is this function of the human voice as a carrier wave for the modulation of speech sounds by articulation, and thus for the audible expression of thoughts, which will be considered in this paper

## LARYNGEAL PATHOLOGY AND PHONATION

The voice can be impaired by many abnormal conditions of the larynx These may be *acute*, like infections, or *chronic*, like permanent changes in structure, further, they may be of *peripheral* origin, such as in laryngeal injury, or of *central* origin, as a result of some brain pathology Previously, one used to differentiate also between *organic* lesions, which would be recognizable by some changes in structure or

# DYSPLASTIC DYSPHONIA

## Minor Anomalies of the Vocal Cords Causing Persistent Hoarseness[*][†]

GODFREY E ARNOLD, M D ,

New York, N Y

### THE SIGNIFICANCE OF THE VOICE FOR COMMUNICATION

Speech is the fundamental prerequisite for the intellectual development and the social integration of man Due to its complex nature and to the manifold relations between speech and all phases of human activity the study of speech is shared by a large number of various sciences Ranging from acoustics to zoology, almost every science shows a well-defined interest in some problems of speech and advances the composite knowledge by specialized contributions

This variety of scholastic viewpoints produced many definitions of the terms dealing with speech Since scientific terminology is fully covered by the disciplines of linguistics, or speech psychology, there is no need to discuss it here, however, the common usage of these terms deviates from academic parlance Let us first clarify some of these discrepancies, particularly with regard to the concepts of language, speech, and voice

*Language* is defined in Webster's dictionary as the generic term, denoting in its most extended use any mode of conveying ideas Tongue is the Anglo-Saxon term for language, especially for spoken language Speech refers to oral communication and represents the faculty of expressing thoughts by audible words or articulate sounds

*Articulation* is the utterance of the elementary sounds of a language by the appropriate movements of the speech

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[*] Read at the First Symposium on Human Communication held at the National Hospital for Speech Disorders in April 1956

[†] From the Diagnostic Services (G E Arnold M D Clinical Director) of the National Hospital for Speech Disorders (Lynwood Heaver M D Director)

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remained isolated contributions to the then obscure correlation of structural peculiarities with losses of function, no general conclusions could be drawn After sufficient evidence had been accumulated it is now possible to arrive at a precise diagnosis in most of these cases

As usual, the case history assists in the differentiation of congenital and acquired conditions, and in addition, may present indications of hereditary or post-mutational types Routine otolaryngologic examination establishes the absence of infections or traumatic ailments If necessary, the customary laboratory and X-ray studies help to rule out general diseases More important is the corroboration of retarded physical maturation, hormonal imbalance, or constitutional debility by similar findings in other parts of the body When, finally, the finding of a congenital laryngeal abnormality can be correlated with the presenting vocal disorder, the diagnosis of dysplastic dysphonia, due to developmental hypoplasia of certain parts of the larynx, can be established with certainty

The psychological report is less helpful in such cases, for it is difficult to distinguish which part of the psychologic deviations, if present, are due to the secondary reaction of the individual to his disability, and which part may have been of primary contributing significance Sometimes, however, the psychologist reports infantilistic signs which then agree well with the concept of a psycho-somatic retardation of the emotional and physical development

## MINOR LARYNGEAL MALFORMATIONS

Since the larynx is a single organ whose two halves pertain to the two sides of the body, it is easy to understand that the slightest irregularity in the development of either side will remain permanently visible in the form of asymmetrical configuration In fact, laryngeal asymmetry had been frequently described by the older authors An abundant variety of such observations had been analyzed in the encyclopedic review by Beck and Schneider (1926) They demonstrated that any part of the larynx may be the seat of congenital motility, and *functional* disorders, which would leave the structure intact while deranging the audible function

Similarly to other medical specialties one has lately recognized that no such artificial division can be made Sometimes marked structural abnormalities may be associated with excellent vocal function In other cases severe functional losses are present in a larynx which appears normal to the eye Between these two extremes are found the large majority of cases showing a combination of these two observations, moreover, the advances of bio-chemical and physiologic research demonstrate well-defined abnormalities in such diseases which were hitherto regarded as functional Schizophrenia is an example Hence, one prefers to classify diseases according to their etiologic causes, at least as far as presently distinguishable With regard to vocal pathology, increasing usage is made of an etiologic terminology, which has replaced the older symptomatologic classifications

## DYSPLASTIC DYSPHONIA

In a large center for voice and speech disorders the exceptional cases are more frequently seen than in a regular clinic for ear, nose, and throat diseases For this reason, we encounter a relatively large number of patients whose hoarseness has been noticed since early childhood Others noticed the onset of their chronic vocal disability at the time of puberty Occasionally, such patients also report that some of their near relatives seem to have a similar disability It would, therefore, appear that there exist *hereditary, congenital,* and *post-mutational* types of chronic hoarseness

Laryngoscopic examination of these patients frequently reveals minor anomalies of the larynx While the well-known signs of the common laryngeal diseases are absent, one finds a great variety of structural abnormalities These affect the dimensions, proportions, relative positions and the bilateral symmetry of all laryngeal parts In previous years such findings were often reported in great detail Obviously, the authors hoped to correlate their visible findings with the audible disorders of the voice While those observations

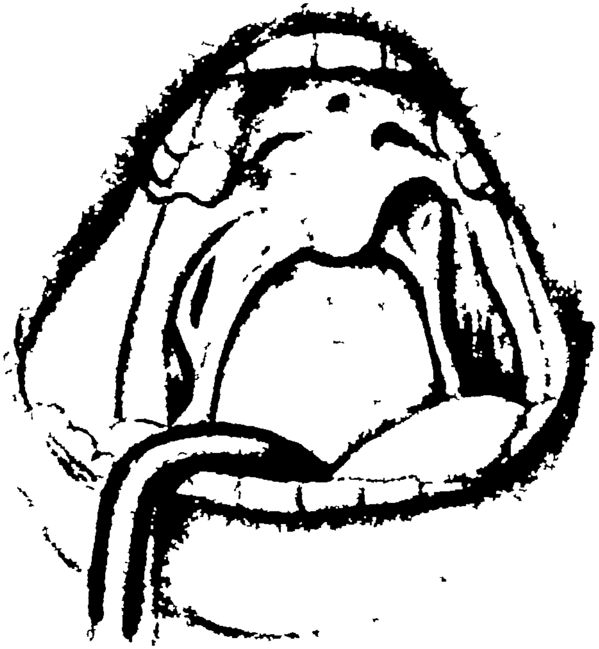

Fig 1 Congenital Malformation and Asymmetry of the Palate

congenital hypoplasia of the right vocal cord, one associated with hypoplasia of the right side of the tongue All three patients suffered from congenital dysplastic dysphonia This combination of laryngeal and lingual asymmetry had also been investigated by Motta In a monograph on the accessory chambers of the larynx, Bartels compared the human anomalies with the anatomical findings in primates and other mammals

Arnold (1947) gave a detailed analysis of a severe larynmalformations Vocal disturbances are to be expected particularly when the vocal cords are affected Other regions may also disturb the voice or add pathologic noises to expiration One example is the pseudo-syrinx described by Jackson and Jackson This is a subglottic stenosis of the trachea which causes dyspnea and a crowing sound on coughing

As is well-known, the vocal cords perform the vibrations which produce the primary laryngeal voice Any irregularity in the length, breadth, thickness, specific weight, muscular development, position, insertion, motility and contractility, in short any asymmetry in the physical properties of the vocal cords must affect the acoustic qualities of the voice

Reker published, in 1938, a detailed phoniatric study of the correlation between minor laryngeal abnormalities and persistent vocal disabilities He came to the conclusion that some of these conditions are hereditary, others are simply present since birth and are called congenital, a third group appears after puberty, apparently being due to a maldevelopment of the infantile into the adult larynx, which would represent a developmental type of dysphonia Since four of his 18 cases showed additional asymmetry of the face, and since five cases revealed palatal asymmetry, he assumed the presence of a generalized constitutional debility of the peripheral organs of speech, at least in those cases Fig 1 shows a case of congenital palatal malformation

This combination of internal asymmetries of the larynx with other visible anomalies was also found by Tarneaud In his monograph on the laryngopathias (1944) he mentioned the combination of laryngeal displacement with spinal skoliosis In some cases the asymmetry of the thyroid cartilage may be felt by the palpating finger Luchsinger mentioned in his textbook (p 98) that these palpable asymmetries are a frequent finding in cases of constitutional weakness of the voice

Similar observations were made by Garde, whose recent case showed unilateral hyperplasia of many skeletal parts on the right side, associated with laryngeal asymmetry and dysplastic dysphonia Luchsinger reported three cases of more noticeable on one side Frequently it is associated with other laryngeal or oral asymmetries (see Fig 3)

This condition is rare as far as the general population is concerned In a specialized voice clinic, however, the sulcus of the vocal cord can be seen quite frequently At the National Hospital we observe a few cases among about 3,000 patients each year Arnold counted 12 cases among 1250 adults (soldiers) who were referred for disorders of voice or speech These figures demonstrate again how statistics can be influenced by selective factors It is obvious that cases of chronic hoarseness tend to concentrate in clinics for the special care of vocal disorders

### TABLE I

### NINE CASES OF LARYNGEAL ASYMMETRY FOUND AMONG 1250 SOLDIERS SUFFERING FROM DISORDERS OF VOICE AND SPEECH

1 Right cord lower than the left with hyperkinetic dysphonia
2 Right cord higher and broader than the left with congenital dysphonia.
3 Hypoplasia of the left cord with congenital dysphonia.
4 Congenital crossing of the arytenoids with secondary laryngitis and congenital dysphonia
5 Same with post mutational falsetto voice
6 Same with psychogenic hyperkinetic dysphonia
7 Same with vocalis insufficiency and habitual mixed dysphonia
8 Right ventricle of Morgagni wider than the left with developmental hypokinetic dysphonia
9 Right ventricle of Morgagni wider than the left with psychogenic hypokinetic aphonia.

The vocal cord sulcus had been repeatedly noted by the older authors Kelemen quoted the autoptic findings of Denker, Giacomini (1892), and Grabert (1914), who studied the larynx of the gorilla and of various human races Salvi is usually credited with the first more complete description of the "sulcus vocalis" in 1901 Following the anthropologic ideas of his time, he considered the sulcus as a degenerative sign, allegedly more frequent among criminals Other authors, like Alézais (1906, 1912), described the condition as "double vocal cords" In 1906 Citelli undertook more extensive regeal malformation with congenital dysphonia History, laryngoscopy, X-rays, anthropological report, and the vocal status led to the diagnosis of a laryngeal fracture during the complicated birth (see Fig 2) Similar to the classifications of other congenital malformations this case demonstrated the necessity of distinguishing between *constitutional* maldevelopments and acquired *connatal* malformations Hence, there exist cases of connatal traumatic dysphonia His nine other observations of laryngeal asymmetry were published

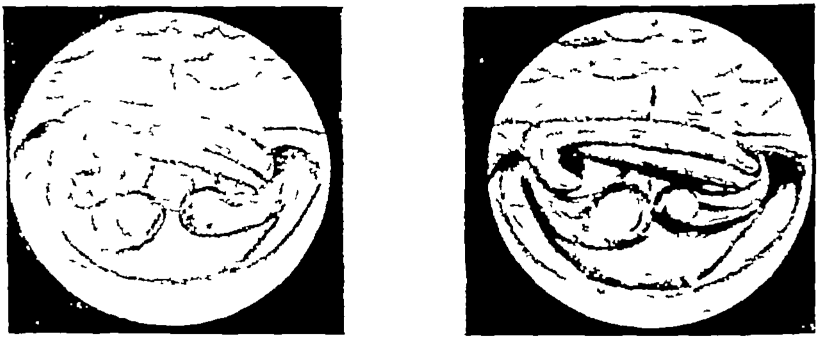

Fig 2 Connatal Malformation of the Larynx due to Laryngeal Fracture by birth injury

in 1948 Table I shows the various forms of asymmetry, and their association with several types of dysphonia, the majority being of congenital origin

### VOCAL CORD SULCUS AND DOUBLE VOCAL CORDS

The vocal cord sulcus is a fine longitudinal furrow on the medial edge of the vocal cord It may extend over the entire length of the cord, or may be limited to a segment of variable length, its depth is also variable, ranging from a faint line to a deep partition of the cord In the latter case it divides the cord into two portions, an upper or lateral lip, and a lower or medial lip This is then called a double vocal cord There may even be an accessory ventricle behind a very deep sulcus The sulcus may be unilateral, bilateral, or may be more noticeable on one side Frequently it is associated with other laryngeal or oral asymmetries (see Fig 3)

This condition is rare as far as the general population is concerned In a specialized voice clinic, however, the sulcus of the vocal cord can be seen quite frequently At the National Hospital we observe a few cases among about 3,000 patients each year Arnold counted 12 cases among 1250 adults

### TABLE I

### NINE CASES OF LARYNGEAL ASYMMETRY FOUND AMONG 1250 SOLDIERS SUFFERING FROM DISORDERS OF VOICE AND SPEECH

1 Right cord lower than the left with hyperkinetic dysphonia
2 Right cord higher and broader than the left with congenital dysphonia
3 Hypoplasia of the left cord with congenital dysphonia
4 Congenital crossing of the arytenoids with secondary laryngitis and congenital dysphonia
5 Same with post mutational falsetto voice
6 Same with psychogenic hyperkinetic dysphonia
7 Same with vocalis insufficiency and habitual mixed dysphonia
8 Right ventricle of Morgagni wider than the left with developmental hypokinetic dysphonia
9 Right ventricle of Morgagni wider than the left with psychogenic hypokinetic aphonia

(soldiers) who were referred for disorders of voice or speech These figures demonstrate again how statistics can be influenced by selective factors It is obvious that cases of chronic hoarseness tend to concentrate in clinics for the special care of vocal disorders

The vocal cord sulcus had been repeatedly noted by the older authors Kelemen quoted the autoptic findings of Denker, Giacomini (1892), and Grabert (1914), who studied the larynx of the gorilla and of various human races Salvi is usually credited with the first more complete description of the "sulcus vocalis" in 1901 Following the anthropologic ideas of his time, he considered the sulcus as a degenerative sign, allegedly more frequent among criminals Other authors, like Alézais (1906, 1912), described the condition as "double vocal cords" In 1906 Citelli undertook more extensive research and found further parallels in the comparative anatomy of animals He coined the term "sulcus glottideus" and claimed to have found it in every second larynx dissected for this purpose Sometimes the sulcus was barely visible with the naked eye Further autopsy findings were reported by Hajek (1928), Demel (1928), Kelemen (1929), and by Frank and Malev (1939)

The first observation on a patient was made by Lautenschlager (1912) He also recognized that the hoarseness was due to the incomplete closure of the glottis, therefore, he suggested that the insufficiency be corrected by the intralaryngeal injection of paraffin, according to the then new method of Brunings In Oertel's case of 1912, an acute inflammation and swelling of the vocal cords temporarily improved the hoarseness which showed again that the dysphonia in a case of vocal cord sulcus was primarily due to the bowing glottis

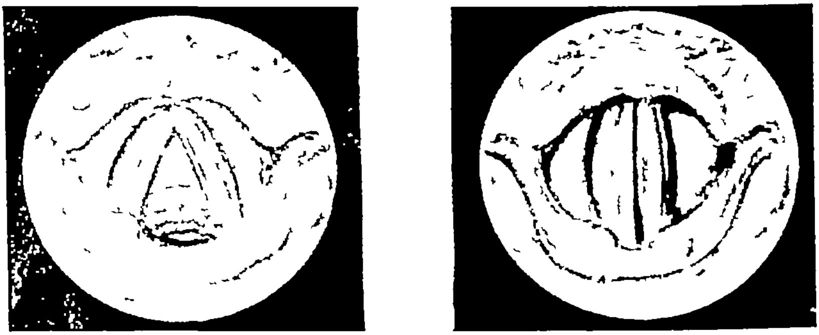

Fig 3 Congenital Asymmetry of the Larynx with Sulcus on Left Cord and Hypoplasia of the Right Ventricular Fold

In 1928 Berger submitted the first phoniatric and stroboscopic analysis of the congenital dysplastic dysphonia due to vocal cord sulcus, or double vocal cords Again, he noted the incomplete closure of the glottis More cases were subsequently described by Van Caneghem (1928), Fornai (1936), Tarneaud (1944), or Delaini and De Stefani (1952) One of their four cases showed hereditary tendencies The largest number of cases was seen by Arnold who, in 1948, reported 12 observations The combination with further laryngeal and oral anomalies in these cases is shown on Table II

For a time some authors disagreed on the possible etiologic factors Bilancioni observed in 1923 the development of a tuberculous ulcer within a preexisting sulcus Kelemen further quoted Spiess (1908), who saw the development of a longitudinal scar as a residue of a healed vocal cord gumma Another opinion in favor of the tuberculous origin was voiced by Van Caneghem (1928), while Garel (1922) believed in a shrinking atrophy following chronic laryngitis If one considers the frequency of tuberculosis, syphilis, or chronic laryngitis at the time of these observations, a coincidental combination of the congenital sulcus with such acquired granulations would not be surprising

TABLE II

12 CASES OF VOCAL CORD SULCUS FOUND AMONG 1250 SOLDIERS SUFFERING FROM DISORDERS OF VOICE AND SPEECH

*1* Sulcus on right cord prolapse of the left arytenoid with congenital hypokinetic dysphonia
*2* Sulcus on both cords hornlike elongation and phonatory crossing of both corniculate tubercles (similar to Blumenfeld s case reproduced by Beck and Schneider on their p 429), absence of both cuneiform tubercles with dysphonia ventricularis
*3* Sulcus on both cords with habitual hyperkinetic dysphonia
*4* Sulcus on both cords with congenital hypokinetic dysphonia
*5* Sulcus on both cords with incomplete mutation of the voice (developmental dysphonia)
*6* Sulcus on both cords with developmental dysphonia and dysphemia (stuttering)
*7* Sulcus on left cord with developmental dysphonia
*8* Sulcus on left cord with habitual mixed dysphonia
*9* Sulcus on left cord deeper than the right asymmetry of Morgagni's ventricles (the right wider than the left) vocalis insufficiency with congenital hypokinetic dysphonia and lisping (see Fig 3)
*10* Sulcus on left cord deeper than the right contact ulcer right vocalis insufficiency anterior ventricular hyperkinesis with congenital hypokinetic dysphonia
*11* Sulcus on left cord deeper than the right palatal asymmetry with developmental dysphonia
*12* Sulcus on left cord with diphtheric vagus paralysis on the right.

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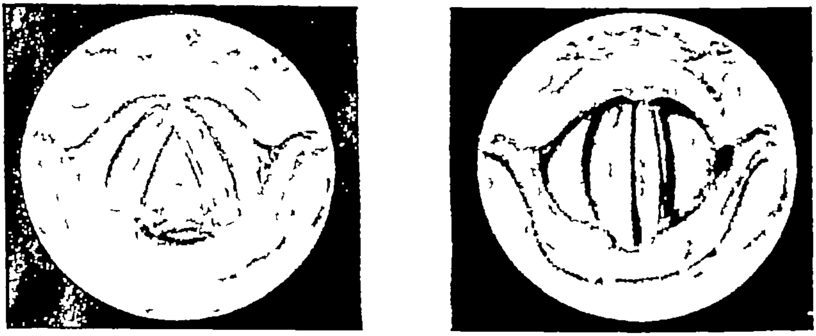

Fig 3 Congenital Asymmetry of the Larynx with Sulcus on Left Cord and Hypoplasia of the Right Ventricular Fold

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Treatment is rather difficult Since the observations of Lautenschlager and Oertel it is well-known that the direct cause of the hoarseness consists of the hypoplasia of the vocalis muscles Because these hypoplastic, asymmetrical, and possibly divided cords do not completely close on phonation, the voice is always accompanied by an escape of air This addition of non-vibrating air to the voice sound is heard as hoarseness Consequently, any surgical attempt at improvement would have to increase the closure of the glottis I intend to follow Réthi's procedure, who corrected the state of myopathic paresis of the vocalis muscles by injecting vaseline into the bowing cords The cartilage paste recommended in another publication (Arnold) for the compensation of adductor paralysis appears suitable also for a congenitally bowing cord Messerklinger and Doubek described the successful correction of a bowing cord due to unilateral congenital sulcus by intra-cordal injection of paraffin by the Brunings method

Vocal rehabilitation by appropriate voice therapy should always be tried In any case one can improve the condition by eliminating the secondary parakinesias so that the patient may learn how to use his voice as well as his anatomical condition will permit Unfortunately, it has to be admitted that the amount of progress is always limited At the present time such voices cannot be greatly improved It is, therefore, most important to advise these patients not to choose an occupation with heavy or specialized demands on the voice Early recognition of the condition is the best service we can presently render to these patients All authors share this prognostic reservation

## REPORT OF A CASE

Case No 71940, Pearl C a white unmarried female age 18, was first seen on February 1 1950 She complained of chronic hoarseness since earliest childhood No other relative has any voice trouble She

All recent authors are in accord with the original discoverers that the vocal cord sulcus is a congenital malformation. Jackson and Jackson, who saw four cases of "supernumerary cords," called it a malformation of atavistic origin. Many authors referred to the normal presence of the sulcus in various animals, ascribing a regressive significance to its occurrence in man (Kelemen, Tarneaud, Delaini and De Stefani, etc.). The latest contribution to this interpretation was made by Sbernini in 1954. Evidence for the normal presence of a sulcus in animals can be found in the papers of Albrecht (1896), Wilson (1910), and particularly by Nemai (1912, 1926). The latter described double vocal cords, divided by a sulcus, in many species: deer, giraffe, antelope, swine, gibbon, etc. In accordance with previous authors, he found these accessory cords most noticeable in primates. It is interesting to note that he considered the development of these accessory cords below the true vocal cords of the gibbon as unfavorable for the vocal abilities of this species. According to Kelemen (1949) the reduplication of the vocal cords is particularly prominent in the chimpanzee larynx. He believes that the double cords are partly responsible for the double tones frequently heard in the voice of the chimpanzee.

## SYMPTOMS OF DYSPLASTIC DYSPHONIA

When listening to this type of voice, one is impressed by a peculiar hollow and unpleasant quality. It is difficult to describe it in words, but it reminds one of the sound made by a broken pot. It seems as though the two cords were out of tune. There is a constant breathy quality due to the excessive escape of air between the bowing cords. Hence, phonation time is short and the volume is weak. The average speaking pitch is often too high, apparently because the high tones are usually clearer. This is due to the bowing glottis, which is physiologic for the male falsetto tones, and, therefore, does not disturb the high tones as much as the low tones. Moreover, the patients tend to abuse their weak voices by faulty attempts at compensation. Instead of exploiting all reserves of projection and resonance, they try to overcome their disability by increased muscular efforts. This leads to various parakinesias, such as phonatory elevation of the larynx, over-

## CONCLUSIONS

The voice is an integral part of the human organs of communication It represents the carrier wave on which are superimposed the modulations of the laryngeal voice sound by the articulatory movements of the speech organs Serving this specific function, the voice should not be confounded with the other components of communication The terms articulation, speech, and language, describe specific aspects of oral communication and cannot be used interchangeably

Laryngeal pathology may disturb the voice in many ways Contrary to the old idea of distinguishing organic and functional vocal disturbances, one now attempts an etiologic classification of the various dysphonias

Dysplastic dysphonia refers to a group of chronic vocal disabilities due to minor anomalies of the larynx They may be of hereditary, congenital, and connatal origin, or they may appear as a result of faulty laryngeal maturation during puberty

The minor laryngeal malformations are characterized by great diversity Their salient feature is an asymmetrical development of the two laryngeal halves, particularly of the vocal cords

A special condition of congenital laryngeal anomaly appears in the form of the vocal cord sulcus If deep enough, it creates the impression of reduplication of the cords All recent authors regard this condition as a congenital anomaly of atavistic or regressive origin

The symptoms of dysplastic dysphonia are well understood and do not present any diagnostic difficulties Regrettably, the same cannot be said regarding treatment One of our cases illustrates this general experience In the future it will be worth while to apply the surgical principles of vocal cord injections Favorable results were shown by Réthi (vaseline), Messerklinger and Doubek (paraffin), and Arnold (cartilage paste) had always enjoyed good health and does not remember any unusual upper respiratory infections or allergies Menstruation is uncomplicated and regular Several previous examinations had reportedly been negative

*General appearance* A slender asthenic, normally developed girl of good intelligence with pleasant manners and an apparently calm temperament No signs of emotional disturbance No signs of anemia or other disease

*Nose and nasopharynx* The mucous membranes are unusually thin, pale and delicate The turbinates are small and the passages open No abnormal secretion no respiratory obstruction

*Mouth* The lips teeth, gums tongue and the palate appear normal Tonsils are absent The oral mucosa is unusually delicate and pale

*Ears and tubes* Very delicate membranes, no pathology

*Larynx* Small but symmetrical All parts are very small and delicately built The mucosa is thin and pale Gross motility is normal The vocal cords are white thin and narrow a longitudinal fine sulcus along the medial border of either side gives the impression of double vocal cords The entrances to the ventricles are very wide During phonation the bowing cords close incompletely leaving an oval glottal chink wide open The vibrations appear to take place between the lower segments of the cords

*Voice* Very hoarse, breathy and weak Average speaking pitch between a $d^1$ (220 294 cps ) Vocal range g $c^2$ (196 523 cps ), no differentiation of registers, the higher tones sound definitely better Phonation time Vowel O on tone $c^1$ 7 8 sec (normal 20 sec ) Marked strain of the external laryngeal muscles is noticeable during phonation

*Speech* No noticeable disorder of articulation, diction or sentence construction

*Diagnosis* Constitutional hypoplasia of all upper respiratory membranes congenital bilateral sulcus with reduplication of vocal cords, congenital hypoplasia of the thyro arytenoid muscles, dysplastic dysphonia hypokinetic type

*Treatment advised* Attempt at vocal rehabilitation by improving resonance, projection and enunciation two sessions per week

*Progress notes* October 4 1950 no change in objective findings but patient believed to be considerably improved December 13, 1950 subjective satisfaction continues August 15, 1951 the voice continues to sound hoarse breathy and shrill October 29, 1951 no change in the bowing of the double cords May 26 1952 although the patient appears very satisfied her voice is as hoarse breathy and harsh as before She left the hospital after having attended more than 200 therapy sessions

In October 1952 she was seen in Bellevue Hospital where we made essentially the same findings and recommendations Apparently the subjective improvement had not been permanent In March 1954 she appeared at the New York Eye and Ear Infirmary, where her congenital vocal disability was interpreted as 'a hysterical speech defect"

*Discharge summary* A case of congenital dysplastic dysphonia had been observed and treated for about four years In accordance with all previous observations no improvement could be achieved An interesting feature in this case was the marked hypoplasia of all visible mucous membranes Finally, the vibrations of the cords seemed to be concentrated on the lower portions of the double cords In contradistinction, most of the previous observers had noted the vibration of the upper segments

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## SUMMARY

The well-known definitions of the various aspects of human oral communication are recalled The basic function of communication is human phonation It may be disturbed by many abnormal conditions, including congenital anomalies of the larynx These malformations may affect all parts of the voice organs, and are particularly harmful to the voice if they disturb the symmetry and fine coordination of the vocal cords One discrete cause of such dysplastic dysphonias is seen in the well-known condition of double vocal cords This disability is described in detail and illustrated by a typical case

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# POST GRADUATE COURSE IN RHINOPLASTY, RECONSTRUCTIVE SURGERY OF NASAL SEPTUM AND OTOPLASTY

An intensive post graduate course in Rhinoplasty, Reconstructive Surgery of the Nasal Septum and Otoplasty will be given July 12, 1958, to July 26, 1958, by Dr Irving B Goldman and staff at the Mount Sinai Hospital, New York, in affiliation with Columbia University

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# AURAL-HARMONIC AND BONE-CONDUCTION THRESHOLDS IN THE EVALUATION OF COCHLEAR RESERVE IN CLINICAL OTOSCLEROSIS[*][†]

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It has been generally accepted for some time that the prognosis for a significant improvement of hearing sensitivity due to operative intervention in the ear with a loss due to clinical otosclerosis depends to a great extent on the adequacy of cochlear function The primary question to be answered by audiologic examination in these cases is this Is the function of the cochlear structures sufficiently normal, as determined by pre-operative functional testing, that significant restoration of hearing sensitivity can be expected in the event of successful operative negation of the conductive impediment due to otosclerosis?

In attempting to test the adequacy of cochlear function, it is important to employ tests that will not be influenced significantly by any physiological abnormality of the middle ear The most widely used procedure in developing an operative prognosis in these cases has been to compare the pure-tone thresholds obtained by air and by bone conduction, sometimes referred to as the "air-bone gap" A number of investigators have attached a great deal of importance to the bone threshold in relation to judging post-fenestration hearing sensitivity

Shambaugh[1] suggested that those ears that are ideal for

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[*] An adaptation of this paper was presented at the 32nd Annual Convention of the American Speech and Hearing Association Chicago November 1956

[†] From the Department of Otolaryngology and the Physiological Acoustics Laboratory University of Michigan Medical School This research was supported in part by the Research and Development Division Office of the Surgeon General Department of the Army under Contract DA-49-007-MD-634

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fenestration have a bone threshold within the normal range at 512, 1024, and 2048 cps. Those suitable but not ideal have abnormal bone-conduction sensitivity at 2048 cps, but normal thresholds at the other two frequencies. He classified those with a bone-conduction audiogram slightly below normal for two or all three of the above frequencies as having a limited and guarded prognosis. In a like manner, Kos and Reger[2] defined three classes of patients as determined by the relation between pre-operative bone and air thresholds. Those in Class I, with the best prognosis for improvement by fenestration surgery, show a bone acuity not exceeding an average loss of 15 db for the frequencies 500, 1000 and 2000 cps. The second class of patients has an average bone acuity exceeding 20 db, but with at least a 30 db gap in the three frequencies. The third class, and that group with the poorest prognosis, is made up of those with a bone acuity exceeding an average loss of 20 db at the three frequencies. Shambaugh and Carhart[3] mentioned that an air-bone gap of less than 35 db is a contraindication for fenestration. They believed that the ideal candidate has a maximum gap of 55 to 60 db and a bone curve within 5 db of the normal zero line.

Pick[4] recently listed what he thought are indications for stapes mobilization, and again the loss by bone conduction was emphasized, as well as the size of the air-bone gap, however, his indications for favorable prognosis were not as conservative as those proposed by other writers in relation to the fenestration procedure.

Personal observations of pre-operative bone-conduction sensitivity measures in otosclerotic ears, coupled with results obtained by other investigators, have led the authors to have certain reservations regarding the validity of air-bone comparisons alone in the judgment of cochlear reserve. It is the purpose of this paper to outline briefly the problems in bone-conduction technique and interpretation, and to discuss the application of a comparatively new technique to the evaluation of cochlear reserve the aural-harmonic (aural-overload) test.*

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*This technique has been referred to as both the aural-harmonic test[24,25,26] and the aural-overload test[19,20,22] The former title is employed in this paper in order to promote consistency in terminology

## BONE-CONDUCTION TESTING

Two of the important parameters in bone-conduction measurement are those of variations in the pressure of the vibrator against the skull, and individual differences in compliance of skin tissue between the vibrator and the mastoid process Goodhill and Holcomb[illegible] found that even when the pressure of the receiver is constant at 400 grams, individual tissue variations may cause an error of 5 db or more in sensitivity They mentioned that bone-conduction results may be "contaminated" by such factors as air-borne sound being radiated by the bone-conduction unit, cartilage conduction from the vibrator to the tympanic membrane, and translational excitation of the ossicular chain due to inertia Carhart[6] discussed other problems, such as faulty audiometer calibration, improper masking techniques, etc At least some of these latter factors exist in any pure-tone audiometric situation, and can be effectively eliminated through careful precautions on the part of the examiner

Even though the above criticisms are of importance, they are somewhat overshadowed by one particular phenomenon peculiar to bone-conduction testing in ears with stapes ankylosis The restriction of stapedial motion relative to the skull seems to decrease substantially the bone-conduction sensitivity in the middle frequencies *in and of itself,* in many cases, even though the anatomic structure of the cochlea and its inherent physiological characteristics are apparently normal This observation was noted by Smith[illegible] when he found such restrictions in a series of cats in which stapedial motion had been mechanically reduced Mean sensitivity to bone-conduction stimulation was lowered 15 db at 500 cps, 20 db at 700 cps, 16 db at 1000 cps, 9 db at 1500 cps and 4 db at 2000 cps after stapes fixation

Various investigators have confirmed this phenomenon in pre- and post-operative examinations of a number of patients with otosclerosis Table I shows the post-operative mean changes in bone-conduction thresholds in a total of 203 patients tested by six investigators Woods[13] found that 90 per cent of 46 cases showed bone-conduction improvement after fenestration and, in five other patients, he found an average increase of 14.2 db. in the speech frequencies.

On the basis of such evidence, Carhart[3,6] proposed that pre-operative bone-conduction thresholds may be corrected 5 db. at 512 cps., 10 db. at 1024 cps., 15 db. at 2048 cps. and 5 db. at 4096 cps., to predict post-operative bone-conduction sensitivity more accurately. Although this concept is important in emphasizing the changing character of bone-conduction sensitivity following surgery, the exact formula for each frequency cannot always be relied upon in an individual case. This fact is amplified in studying not only the mean changes in bone conduction found by other investigators in terms of the apparent discrepancies in discrete thresholds from one group to another (see Table I), but, more significantly, in viewing the results obtained in individual cases. It is also necessary to keep in mind that Carhart's observations were made on ears that had undergone fenestration surgery. Because of the obvious differences in the concomitant anatomic and physiological characteristics of the middle ear following the fenestration operation, as compared to stapes mobilization surgery, it is apparent that complete reliance cannot be placed on the "otosclerotic notch" principle when stapes mobilization is the procedure of choice, until further research is conducted.

TABLE I

MEAN CHANGES IN BONE CONDUCTION SENSITIVITY FOLLOWING FENESTRATION SURGERY IN A TOTAL OF 203 EARS

| Author | Reference No. | No. Ears | Bone-Conduction Improvement—Decibels 500 cps. | 1000 cps. | 2000 cps. | 4000 cps. |
|---|---|---|---|---|---|---|
| Henner | 8 | 72 | 2.5 | 8.7 | 8.2 | 7.5 |
| Juers | 9 | 28 | 3.0 | 4.2 | 13.0 | |
| McConnell and Carhart | 10 | 58 | 1.4 | 6.5 | 8.5 | 4.2 |
| Nilsson | 11 | 10 | 6.0 | 7.0 | 14.0 | 4.0 |
| Sohoel* | 12 | 35 | 15.0 | 12.0 | 11.0 | –2.0 |

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*The purpose of this recent investigation was to emphasize the changing character of bone sensitivity immediately following surgery. The thresholds quoted here were made three weeks post-operatively and were of a stable character. The bone-conduction vibrator was applied to the forehead of all the patients tested in this particular study and the ear not under test was masked.

Some of the physiological concepts that must be kept in mind in attempting to evaluate the bone threshold in losses due to otosclerosis will be reviewed and discussed later.

Because the accuracy of sensitivity thresholds made by bone conduction in the otosclerotic ear is at least questionable with respect to the judgment of cochlear reserve, bone-conduction sensitivity was compared with measurements obtained on the aural-harmonic test pre- and post-operatively. The latter procedure employs an entirely different physiological principle than does bone-conduction testing, and purports to be a direct measure of cochlear function.

## THE AURAL-HARMONIC TEST

The aural-harmonic (aural-overload) test is based on the observation that if a tone is presented to the ear at a sufficiently high intensity, the structures of the organ of Corti will not respond with normal fidelity.[15, 16] This phenomenon is known as amplitude distortion or, more descriptively, aural overload. It has been found that not only is this distortion process a cochlear phenomenon,[17] but that, in the event the structures of the inner ear are damaged or are not functioning normally, the sensation level at which distortion begins to appear is lower than normal.[18, 19, 20, 21, 22, 25, 26]

To achieve the sensation level at which distortion occurs, some method must be employed by which the subject can communicate the emergence of this phenomenon to the examiner. This may be done by employing a variation of the classic exploring-tone method.[23] A pure tone (in this case 1000 or 2000 cps.) is introduced into the ear, and is gradually raised in intensity until distortion first appears. This tone is referred to as the fundamental. When distortion occurs, the amount of acoustic energy which cannot be linearly transmitted by the cochlear structures involved is converted into harmonics of the fundamental tone; however, the untrained subject usually cannot hear these harmonics in his own ear because of the comparative loudness of the fundamental tone. In consequence, the exploring-tone method is employed to enable the subject to report the presence of the harmonics in the form of a sensation of beats.

after fenestration and, in five other patients, he found an average increase of 14 2 db in the speech frequencies

On the basis of such evidence, Carhart[10] proposed that pre-operative bone-conduction thresholds may be corrected 5 db at 512 cps, 10 db at 1021 cps, 15 db at 2048 cps and 5 db at 4096 cps, to predict post-operative bone-conduction sensitivity more accurately Although this concept is important in emphasizing the changing character of bone-conduction sensitivity following surgery, the exact formula for each frequency cannot always be relied upon in an individual case This fact is amplified in studying not only the mean changes in bone conduction found by other investigators in terms of the apparent discrepancies in discrete thresholds from one group to another (see Table I), but, more significantly, in viewing the results obtained in individual cases It is also necessary to keep in mind that Carhart's observations were made on ears that had undergone fenestration surgery Because of the obvious differences in the concomitant anatomic and physiological characteristics of the middle ear following the fenestration operation, as compared to stapes mobilization surgery, it is apparent that complete reliance cannot be placed on the "otosclerotic notch" principle when stapes mobilization is the procedure of choice, until further research is conducted

TABLE I

MEAN CHANGES IN BONE CONDUCTION SENSITIVITY FOLLOWING FENESTRATION SURGERY IN A TOTAL OF 203 EARS

| Author | Reference No | No Ears | Bone-Conduction Improvement—Decibels 500 cps | 1000 cps | 2000 cps | 4000 cps |
|---|---|---|---|---|---|---|
| Henner | 8 | 72 | 2 5 | 8 7 | 8 2 | 7 5 |
| Juers | 9 | 28 | 3 0 | 1 2 | 13 0 | |
| McConnell and Carhart | 10 | 58 | 1 1 | 6 5 | 8 5 | 1 2 |
| Nilsson | 11 | 10 | 6 0 | 7 0 | 11 0 | 1 0 |
| Söhoel* | 12 | 35 | 15 0 | 12 0 | 11 0 | -2 0 |

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* The purpose of this recent investigation was to emphasize the changin character of bone sensitivity immediately following surgery The thresh olds quoted here were made three weeks post operatively, and were of a stable character The bone conduction vibrator was applied to the fore head of all the patients tested in this particular study, and the ear not under test was masked

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When a 1000 cps fundamental tone is introduced into the ear, for example, an exploring tone of 2004 cps is also led to the ear at an intensity level slightly less than the level of the fundamental When the intensity of the fundamental is sufficiently high to produce aural distortion, the subject will hear four beats per second in the background of the fundamental These beats are produced through the interaction of the 2004 cps exploring tone with the 2000 cps second harmonic of the fundamental generated in the inner ear When these beats are heard, the intensities of both the fundamental and the exploring tone are equally reduced until the subject no longer hears the beats The intensity of the fundamental at which these beats are first detected is called the aural-harmonic, or aural-overload, threshold, and the number of decibels between sensitivity threshold and the detection threshold of the aural-harmonic is the linear range of hearing at

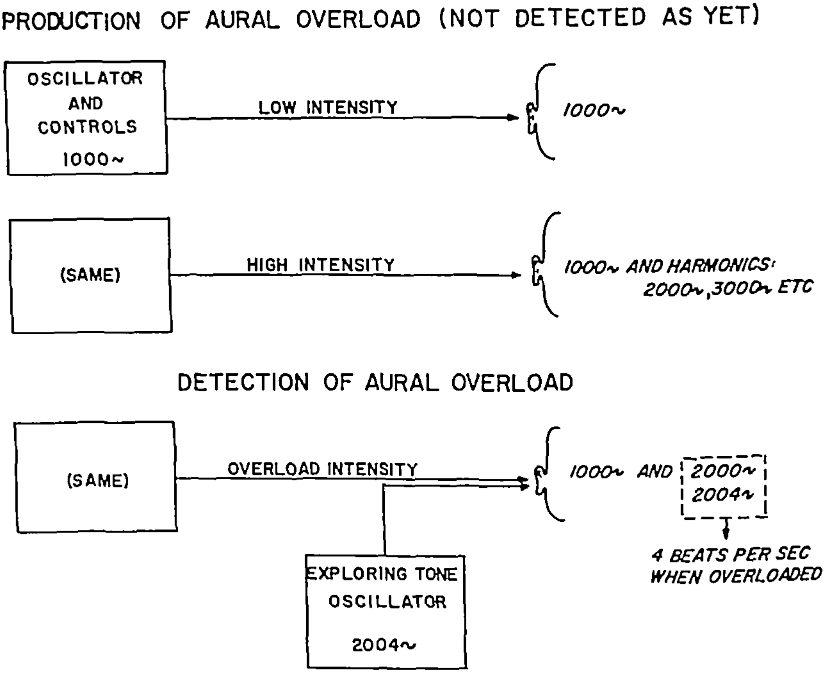
PRODUCTION OF AURAL OVERLOAD (NOT DETECTED AS YET)
OSCILLATOR AND CONTROLS 1000~
LOW INTENSITY
1000~
(SAME)
HIGH INTENSITY
1000~ AND HARMONICS: 2000~, 3000~ ETC
DETECTION OF AURAL OVERLOAD
(SAME)
OVERLOAD INTENSITY
1000~ AND 2000~ 2004~
4 BEATS PER SEC WHEN OVERLOADED
EXPLORING TONE OSCILLATOR 2004~

Fig 1 Schematic diagram of the technique employed in detecting the aural-harmonic (aural-overload) threshold

the particular fundamental frequency being tested A simple illustration of the procedure involved in this test is given in Fig 1

Lawrence and Yantis[19] found, in over 130 normal ears, that the mean range at 1000 cps was 52 db and 57 db at 2000 cps Means obtained in abnormal ears were published in the last-cited study, but since that time a larger number of cases tested in this clinic have been added to the original data to give the mean values listed in Table II *

TABLE II

MEAN AURAL-HARMONIC THRESHOLDS OBTAINED IN NORMAL AND ABNORMAL EARS

| Category | No Ears | 1000 cps Mean (db ) | 1000 cps Stand Dev (db ) | No Ears | 2000 cps Mean (db ) | 2000 cps Stand Dev (db ) |
|---|---|---|---|---|---|---|
| Normal Ears | 145 | 52 | 13 | 133 | 57 | 17 |
| Middle-ear Pathology* | 34 | 45 | 6 | 36 | 48 | 8 |
| Cochlear Pathology | 33 | 13 | 9 | 40 | 19 | 11 |

*These figures do not include the aural-harmonic data obtained in the ears reported in this study

Three investigators, employing different fundamental and exploring-tone frequencies, have reported mean thresholds closely comparable to those of Lawrence and Yantis Sokolowski,[24] using a 500 cps fundamental tone applied by air conduction and a 1003 cps exploring tone by bone conduction, found harmonic thresholds in normal ears from 45 to 50 db above the fundamental-tone threshold In losses of a conductive type, the threshold was essentially the same in sensation level, however, in perceptive losses with recruitment, Sokolowski found the aural-harmonic threshold to be only slightly higher than the intensity of the 500 cps fundamental tone, providing the extent of the loss exceeded 45 to 50 db Opheim and Flottorp,[25] using fundamental frequencies of 250 and 500 cps , found no difference between normal harmonic thresholds and those in ears with conductive losses, but markedly restricted ranges in 70 out of 73 ears with recruitment were recorded They also found the test very helpful in the differential diagnosis of Meniere's disease [26]

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*Through a mathematical error the means and standard deviations of harmonic thresholds measured at 1000 cps in the 17 ears with cochlear involvement were incorrectly stated in the article by Lawrence and Yantis[19] and in the paper by Yantis[20] In both of these publications the mean range of linearity between audibility threshold and harmonic threshold was given as 24 db and the standard deviation as 14 db The correct calculations are a mean of 12 db and a standard deviation of 7 db This correction is incorporated in the data of Table II

Since the aural-harmonic test employs the air-conduction pathway rather than the osseous route, it seems to be a measure of cochlear function not significantly influenced by the physiological status of the middle ear, and may hold some promise of being a comparatively *quantitative* measure of cochlear function Accordingly, this procedure was compared with bone-conduction testing pre- and post-operatively with respect to the relative stability of the two tests under conditions of stapes ankylosis and improved hearing after surgical intervention

## PROCEDURE

The nineteen patients tested in this study were examined in the Department of Otolaryngology, University Hospital Each patient was given a complete pure-tone audiometric examination at least three times before the aural-harmonic test, with at least a one-month interval between each examination The audiogram accepted as each patient's pre-operative threshold pattern was an average of the three audiometric examinations conducted

Pure-tone audiometric and aural-harmonic tests were repeated no less than one-and-one-half months post-operatively in those patients who submitted to fenestration surgery, and when necessary, after stapes mobilization This was done to reduce to a minimum any possibility of the contamination of sensitivity measures by labyrinthine after-effects of surgery (see Sohoel[12])

Pure-tone audiometric tests by air and bone conduction were carried out, using a calibrated Maico H-1 clinical audiometer Traditional audiometric techniques were employed, including the use of masking when necessary All tests on each subject were made with the same equipment and technique, and by the same examiner

In attempting to reduce maximally the effects of the possible paramaters in bone-conduction technique outlined earlier, the following points were consistently followed in testing the patients used in this study

*1* Calibration of the bone-conduction vibrator was carried out, using Carhart's method of air and bone comparisons in normal ears and ears with a moderate pure perceptive loss[6]

*2* During all bone-conduction tests, the vibrator was held against the skull by a headband attached on the opposite side of the head to an earphone The latter was placed over the external meatus of the ear not under test in all patients, whether masking was employed in the opposite ear or not No means of keeping the pressure of the vibrator constant for all the ears tested was used, other than that of securing the vibrator as tightly as possible without causing pain or discomfort

*3* In all cases, the exact position of the vibrator postauricularly was determined by ascertaining the best position to obtain the lowest sensitivity threshold for a 1000 cps tone The position decided upon was permanently used for all frequencies tested on any one ear Repositioning was always carried out in subsequent sessions

*4* When masking was employed, careful attention was given to the intensity of the complex-noise masking signal to eliminate the possibility of trans-cranial conduction of the noise

Aural-harmonic tests were carried out with carefully calibrated equipment especially designed for clinical use* A detailed account of the original laboratory equipment used in previous experimentation is fully described elsewhere.[18, 19] Very briefly, the technique employed in clinical testing was as follows

*1* The patient is instructed that he will hear a loud, steady tone, and that he should listen in the background of that tone for a wavy, or beating sensation If he hears only a qualitative sensation of steadiness, he is asked to say "steady" after listening briefly to the tone If he hears a beating sensation, he is requested to say "beat" Variations on this basic set of instructions are sometimes made if there is any doubt that the patient does not understand

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*For the harmonic-detection measurements made in this study a clinical instrument designed and manufactured by Maico Electronics Inc was employed. The inherent distortion characteristics of the fundamental-tone oscillator were found to be very low the second harmonic of the two fundamental tones was more than 60 db below the acoustic level of the fundamental This factor is of course extremely important in order to eliminate the possibility of intermodulation distortion occurring in the stimulus itself[illegible]

*2* The fundamental tone (either 1000 or 2000 cps ) is then set to an entensity up to 70 db above audibility threshold for that tone The exploring-tone frequency is then made to differ from the second harmonic of the fundamental by approximately 4 cps , and is originally adjusted to be 10 db below the intensity of the fundamental tone These adjustments are made without stimulation of the ear under test

*3* The two tones are then mixed and presented to the ear being tested In most cases the patient hears beats with only a slight adjustment of the exploring-tone intensity If beats are not readily perceptible, then various techniques may be employed

*a* The levels of both tones may be raised equally

*b* The level of the exploring tone may be varied

*c* The exploring tone may be turned off and on for a short time

*d* Combinations of the above may be employed

*4* Upon hearing beats, the levels of both tones are commonly attenuated until the subject no longer hears the beats If beats are still not heard after decreasing the level of the exploring tone, the level of the fundamental tone is recorded and considered to be the aural-harmonic threshold The linear range is determined by substracting the audibility threshold for the fundamental tone from the intensity above normal audiometric zero at which the harmonic threshold was obtained

*5* The linear range is checked by carrying out the test from below the harmonic threshold previously obtained

For the purposes of this study, a range from audibility threshold to aural-harmonic threshold at either 1000 or 2000 cps that is less than 35 db (approximately one standard deviation from the mean in normal ears or in cases of conductive loss) is taken as indicative of abnormal cochlear function

## RESULTS

The sex, age, ear operated upon and the type of operation performed are identified for each case in Table III Ten males and nine females were examined in this study, the age range was from 21 to 52 years, with a mean of 35 years A total of 20 ears was tested, since Case 14 was operated upon bilaterally Data were completely gathered on 19 ears at 1000 cps, and 17 ears at 2000 cps Of the 20 ears tested, the fenestration operation was performed on seven and stapes mobilization was carried out on the remaining 13

TABLE III

IDENTIFYING DATA ON EACH OF THE NINETEEN PATIENTS (TWENTY EARS) TESTED

| Case No | Sex | Age | Ear | Operation |
|---|---|---|---|---|
| 1 | F | 28 | Lt | Fenestration |
| 2 | M | 29 | Lt | Fenestration |
| 3 | M | 52 | Rt | Fenestration |
| 4 | F | 21 | Lt | Stapes Mobilization |
| 5 | F | 41 | Lt | Stapes Mobilization |
| 6 | F | 29 | Rt | Fenestration |
| 7 | F | 34 | Rt | Fenestration |
| 8 | F | 35 | Rt | Stapes Mobilization |
| 9 | M | 52 | Lt | Stapes Mobilization |
| 10 | M | 31 | Rt | Stapes Mobilization |
| 11 | F | 29 | Lt | Fenestration |
| 12 | F | 52 | Lt | Stapes Mobilization |
| 13 | F | 43 | Lt | Stapes Mobilization |
| 14 | M | 39 | Rt | Stapes Mobilization |
|  |  |  | Lt | Stapes Mobilization |
| 15 | M | 36 | Rt | Stapes Mobilization |
| 16 | M | 32 | Rt | Stapes Mobilization |
| 17 | M | 26 | Lt | Stapes Mobilization |
| 18 | M | 22 | Rt | Fenestration |
| 19 | M | 21 | Rt | Stapes Mobilization |

*Group Observations* Because the aural-harmonic test was administered using fundamental tones of 1000 and 2000 cps only, Table IV presents the gross data for all measures taken on each of the subjects at these two frequencies only The first group of seven cases are those on which the fenestration operation was performed, and the remaining cases submitted to the stapes-mobilization procedure The means for the two separate groups, as well as the entire sample, are provided in the Table The data obtained by air- and bone-conduction studies were eliminated for those ears in which aural-harmonic data were incomplete Arithmetical calculations were carried to the nearest whole number

Case 4, which will be examined in detail later, showed a marked decrease in air and bone sensitivity and in the harmonic threshold following surgery Because there was reason to believe that the negative result was due to the operative procedure rather than to poor cochlear reserve pre-operatively, the data collected on this case were not used in calculating means

Except for Case 4, every patient showed an improvement in air-conduction sensitivity at both frequencies in question, ranging from 5 to 40 db (mean of 22 db ) at 1000 cps and from 10 to 30 db (mean of 19 db ) at 2000 cps

Again excluding Case 4, bone-conduction sensitivity improved from 5 to 30 db in 15 ears in the 1000 cps column, and from 5 to 20 db in 12 ears in the 2000 cps column The remaining showed no improvement in bone conduction, which was consistent at both frequencies for Case 10 and for Case 14 in the right ear The mean improvement in bone conduction for all of the ears tested at 1000 cps was 10 db and 9 db for those tested at 2000 cps

All of the cases completely tested in this study had a pre-operative linear range of hearing of 35 db or greater, meeting the requirements of normal cochlear reserve

A discrete aural-harmonic threshold was not obtained in Case 17 at 1000 cps , and in Cases 11, 12 and 15 at 2000 cps This was due to the intensity restrictions of the fundamental tone in the clinical equipment used The maximum intensity available at either frequency was 100 db *re* audiometric zero In all of the cases in which pre-operative thresholds

TABLE IV

THRESHOLD DATA OBTAINED IN EACH EAR COMPLETELY TESTED—IN DECIBELS

| | | 1000 cps | | | | | | | | | 2000 cps | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Air Conduction | | | Bone Conduction | | | Harmonic Thresh | | | Air Conduction | | | Bone Conduction | | | Harmonic Thresh | | |
| | No | Pre-op | Post op | Chg | Pre-op | Post-op | Chg | Pre op | Post op | Chg | Pre-op | Post-op | Chg | Pre-op | Post-op | Chg | Pre-op | Post-op | Chg |
| FENESTRATION | 1 | 50 | 25 | 25 | 20 | 15 | 5 | 40 | 50 | 10 | 50 | 25 | 25 | 10 | 5 | 5 | 45 | 50 | 5 |
| | 2 | 50 | 10 | 40 | 10 | −10 | 20 | 50 | 55 | 5 | 50 | 25 | 25 | 15 | −5 | 20 | 40 | 45 | 5 |
| | 3 | 50 | 45 | 5 | 15 | 10 | 5 | 15 | 10 | −5 | 45 | 35 | 10 | 20 | 20 | 0 | 35 | 35 | 0 |
| | 6 | 40 | 20 | 20 | 15 | −5 | 20 | 45 | 45 | 0 | 25 | 5 | 20 | 5 | −5 | 10 | 50 | 45 | −5 |
| | 7 | 50 | 25 | 25 | 10 | −5 | 15 | 35 | 40 | 5 | 30 | 10 | 20 | 5 | −10 | 15 | 65 | 60 | −5 |
| | 11 | 60 | 30 | 30 | 25 | −5 | 30 | 40 | 50 | 10 | | | | | | | | | |
| | 18 | 35 | 5 | 30 | 15 | 0 | 15 | 10 | 10 | 0 | 35 | 10 | 25 | 5 | −10 | 15 | 55 | 55 | 0 |
| | Mean | 48 | 23 | 25 | 16 | 0 | 16 | 43 | 46 | 3 | 39 | 18 | 21 | 10 | −1 | 11 | 48 | 48 | 0 |
| STAPES MOBILIZATION | 4* | 30 | 50 | −20 | 5 | 15 | −10 | 40 | 35 | −5 | 30 | 55 | −25 | 5 | 20 | −15 | 40 | 30 | −10 |
| | 5 | 25 | 15 | 10 | 10 | 0 | 10 | 50 | 50 | 0 | 35 | 25 | 10 | 30 | 15 | 15 | 50 | 50 | 0 |
| | 8 | 45 | 30 | 15 | 20 | 0 | 20 | 35 | 40 | 5 | 45 | 30 | 15 | 20 | 0 | 20 | 45 | 50 | 5 |
| | 9 | 55 | 35 | 20 | 15 | 10 | 5 | 35 | 30 | −5 | 45 | 25 | 20 | 15 | 0 | 15 | 55 | 50 | −5 |
| | 10 | 30 | 20 | 10 | 20 | 20 | 0 | 40 | 40 | 0 | 20 | 10 | 10 | 10 | 10 | 0 | 50 | 55 | 5 |
| | 12 | 40 | 10 | 30 | −5 | −10 | 5 | 45 | 45 | 0 | | | | | | | | | |
| | 13 | 40 | 15 | 25 | 5 | 5 | 0 | 55 | 65 | 10 | 35 | 20 | 15 | 5 | 0 | 5 | 60 | 65 | 5 |
| | 11 | 40 | 10 | 30 | 5 | 5 | 0 | 50 | 50 | 0 | 25 | 15 | 10 | −5 | −5 | 0 | 65 | 55 | −10 |
| | | 35 | 0 | 35 | 10 | 0 | 10 | 55 | 55 | 0 | 25 | 0 | 25 | −5 | −5 | 0 | 55 | 55 | 0 |
| | 15 | 30 | 15 | 15 | 15 | 5 | 10 | 60 | 65 | 5 | | | | | | | | | |
| | 16 | 45 | 25 | 20 | 15 | 5 | 10 | 40 | 45 | 5 | 40 | 25 | 15 | 10 | 0 | 10 | 45 | 45 | 0 |
| | 17 | | | | | | | | | | 45 | 15 | 30 | 15 | 10 | 5 | 45 | 45 | 0 |
| | 19 | 25 | 5 | 20 | 10 | 5 | 5 | 55 | 55 | 0 | 30 | 0 | 30 | 15 | 0 | 15 | 55 | 55 | 0 |
| | Mean* | 37 | 16 | 21 | 11 | 4 | 7 | 47 | 49 | 2 | 35 | 17 | 18 | 11 | 3 | 8 | 53 | 53 | 0 |
| | Total M* | 41 | 19 | 22 | 13 | 3 | 10 | 45 | 48 | 3 | 36 | 17 | 19 | 11 | 2 | 9 | 51 | 51 | 0 |

*Results obtained in Case 4 were not included in the calculation of the sub-group or total mean data See Results for the reason for this omission could not be obtained, this intensity was not sufficiently high to produce aural harmonics, however, in all of these ears, no evidence of amplitude distortion was detected at a sensation level of less than 50 db, thus connoting normal cochlear reserve under the terms of delineation accepted for this study

The harmonic threshold at 1000 cps changed post-operatively from a linear range that was 5 db less than the pre-operative level to one that was 10 db more than this intensity, at 2000 cps the range was from 10 db less to 5 db more Thus there was never more than a 10 db change from the pre-operative to the post-operative linear range of hearing for any patient tested Considering that there is at least a 5 db error of measurement accepted in almost all clinical audiometry involving intensity increments of 5 db, this seems quite stable The mean change was 3 db at 1000 cps, and 0 db at 2000 cps In no case in which there was post-operative improvement in air conduction did the harmonic threshold decrease or increase post-operatively beyond one standard deviation from the normal mean as given in Table II

Because of the comparative size of the samples, no attempt was made to compare the results statistically in terms of the two types of operations employed, however, it is interesting to note that the greatest mean improvement in air and bone conduction at 1000 cps occurred in the "fenestrated" group (25 and 16 db respectively, as compared with 21 and 7 db for the "mobilized" group) At 2000 cps there was also slightly more improvement in air conduction in the "fenestrated" group (21 db compared to 18 db) and in bone conduction (11 db and 8 db respectively)

Fig 2 is a composite audiogram of the mean pre- and post-operative air and bone-conduction thresholds for the entire group The mean harmonic thresholds are also provided It is immediately apparent upon examining the changes occurring in hearing sensitivity for the three tests employed that there is a definite mean improvement in air and bone sensitivity for pure tones but, comparatively, an extremely small change, if any, in the linear range of hearing for the entire sample

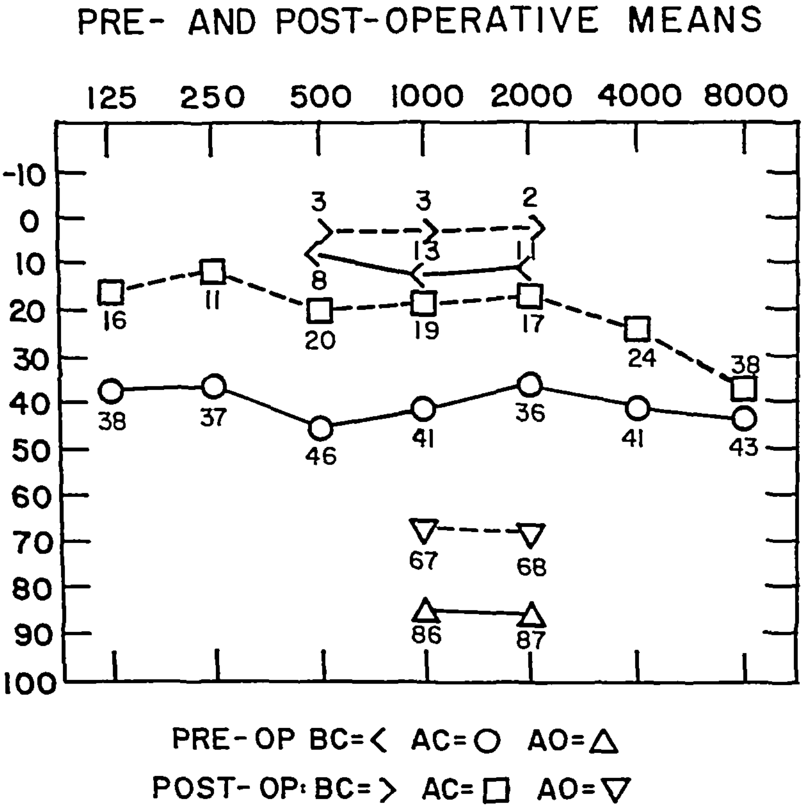
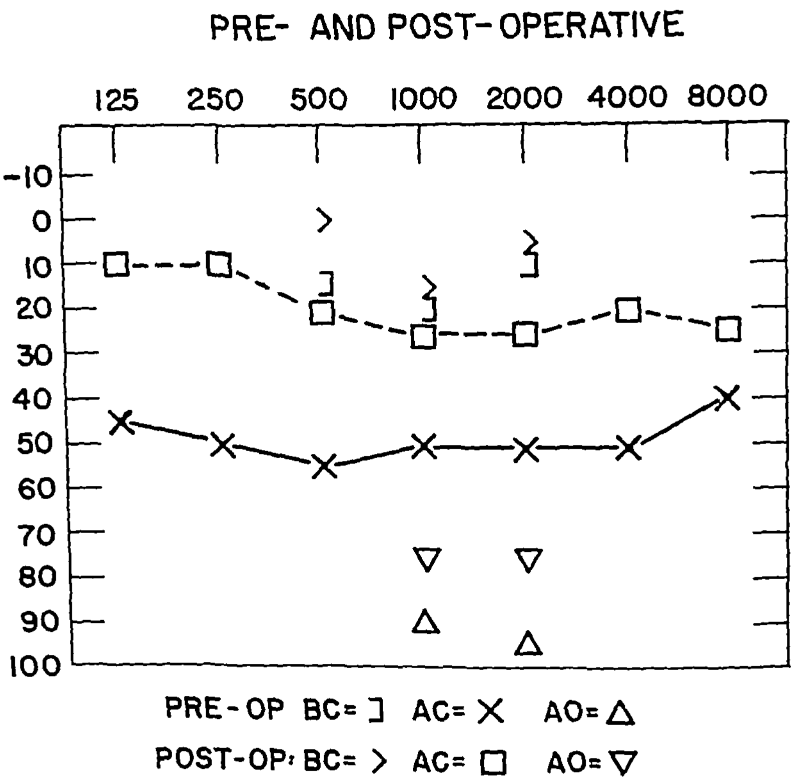


Fig 2 Graphic representation of the mean pre- and postoperative thresholds for air conduction bone conduction and aural-harmonics found in the ears in which all three tests were conducted in this study The numerical mean thresholds are recorded AO refers to the aural-harmonic (aural-overload) threshold

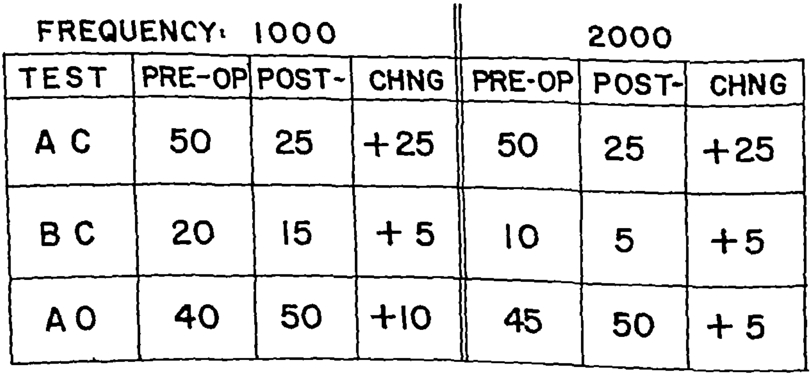
*Illustrative Cases* In order to demonstrate the particular types of problems and results that arise in individual cases and to illustrate the differences that can occur between patients, the results obtained in the first five ears tested are presented and discussed The pre- and post-operative air, bone and harmonic thresholds *re* audiometric zero are presented in the figure referred to for each case

*Case No 1* (see Fig 3) Female age 28 years Left fenestration The pre-operative air and bone sensitivity in this case presents a good prognosis for operative intervention There is an air bone gap of 30 db at 1000 cps and a gap of 40 db at 2000 cps A normal linear range from air-conduction threshold to the aural harmonic threshold confirms the presence of good cochlear reserve



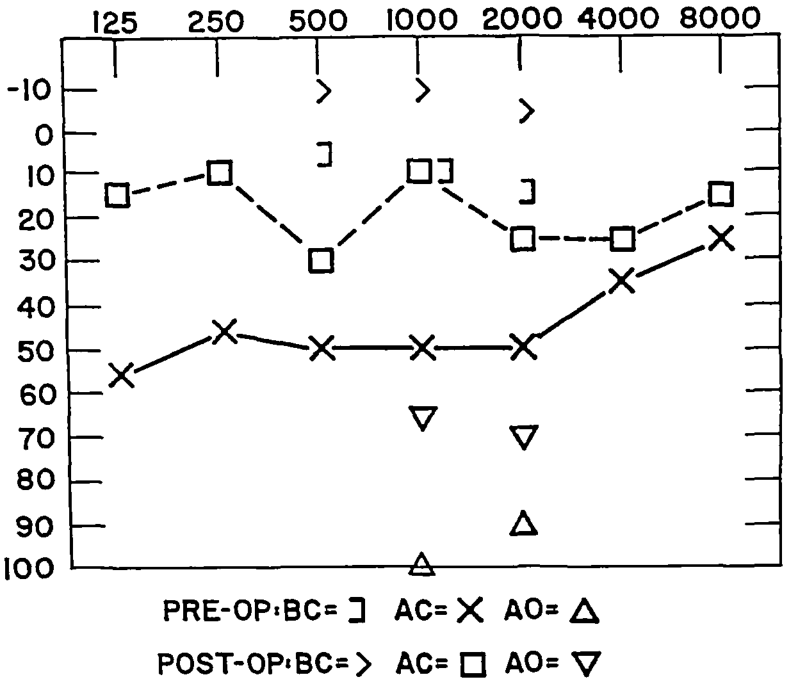
PRE- AND POST-OPERATIVE

AUDIOMETRIC DATA



| FREQUENCY: | 1000 | | | 2000 | | |
|---|---|---|---|---|---|---|
| TEST | PRE-OP | POST- | CHNG | PRE-OP | POST- | CHNG |
| A C | 50 | 25 | +25 | 50 | 25 | +25 |
| B C | 20 | 15 | + 5 | 10 | 5 | +5 |
| A O | 40 | 50 | +10 | 45 | 50 | + 5 |

Fig 3 Results obtained in Case No 1


PRE- AND POST-OPERATIVE

AUDIOMETRIC DATA

| FREQUENCY= | 1000 | | | 2000 | | |
|---|---|---|---|---|---|---|
| TEST | PRE-OP | POST- | CHNG | PRE-OP | POST- | CHNG |
| A.C | 50 | 10 | +40 | 50 | 25 | +25 |
| B C | 10 | -10 | +20 | 15 | -5 | +20 |
| A.O | 50 | 55 | +5 | 40 | 45 | +5 |

Fig 4 Results obtained in Case No 2

Post operatively the good prognosis for air conduction improvement is borne out by a significant rise in air conduction sensitivity, providing socially adequate hearing in the operated ear, however the expected improvement in bone conduction is not large only 5 db at the two frequencies of interest Harmonic thresholds are improved slightly, and are still well within one standard deviation of the normal mean

The important fact illustrated here is that although in the large number of cases there is an expected improvement in bone sensitivity post-operatively it cannot always be relied upon in individual cases In this patient there was enough of an air bone gap to insure at least fair cochlear reserve and the results of harmonic threshold studies provided secure reinforcement of this conclusion

*Case No 2* (see Fig 4) Male age 29 years Left fenestration The results obtained in this case illustrate quite remarkably the comparatively stable characteristic of the linear range of hearing after successful surgery as opposed to a large change in bone-conduction sensitivity, and shows the changing vs stable' quality of the two tests that is generally found It is evident that the pre-operative bone-conduction measurements were actually inaccurate to the extent of 20 db at 1000 and 2000 cps which is even a greater degree of inadequacy than could be accounted for by the application of the Carhart "notch" formula Again the possibility of good cochlear reserve was confirmed by a normal linear range of hearing

*Case No 3* (see Fig 5) Male age 52 years Right fenestration At first examination the data collected on this patient were almost identical before and after surgery at least at the middle frequencies of interest in this study On the basis of the pre-operative air and bone threshold alone the prognosis would have been good, especially after applying the "notch' formula for bone-threshold corrections Nothing abnormal was noted in the pre-operative aural harmonic threshold at 1000 cps however, the linear range at 2000 cps was comparatively restricted and a guarded prognosis based upon selectively questionable cochlear reserve at 2000 cps was made

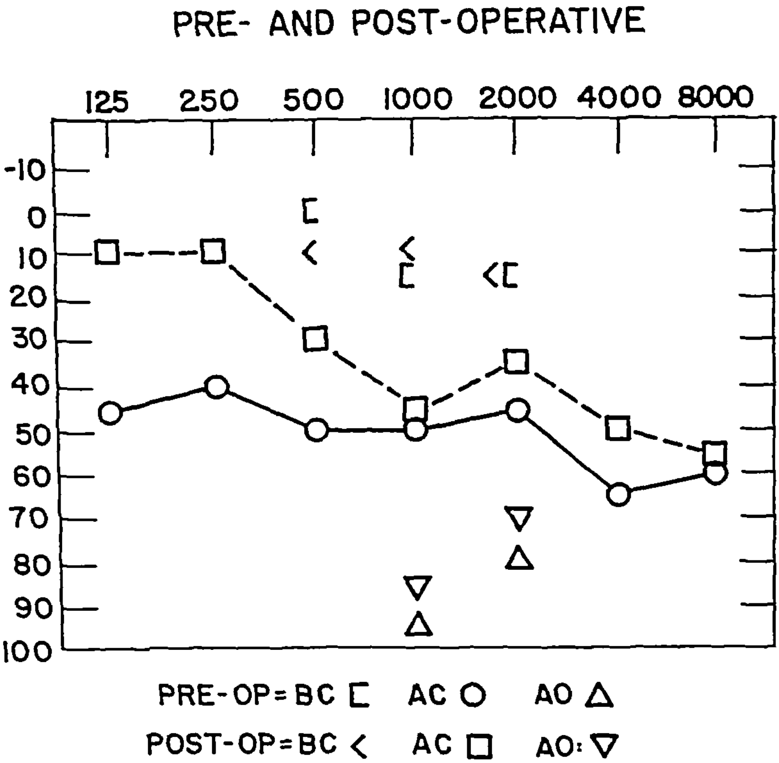
Because of the normal linear range at 1000 cps surgery was carried out Post operatively there was significant improvement in air conduction sensitivity for the lower frequencies but very little at 1000 cps and 2000 cps Bone conduction improved only 5 db at 1000 cps and remained stable at 2000 cps The harmonic thresholds remained essentially the same

In retrospect it is assumed that the slightly restricted and unchanged linear range at 2000 cps indicated localized cochlear pathology at least involving the higher frequencies This seems to be confirmed by the unchanged loss in bone sensitivity at 2000 cps and the lack of improvement in air conduction post operatively which is associated only with the higher frequencies

*Case No 4* (see Fig 6) Female age 21 years Left stapes mobilization Although the outcome of surgery in this case was unfortunate it is chosen to illustrate the use of the aural harmonic test in determining the locus of damage in an unsuccessful procedure

Pre-operatively the test results were consistent with a diagnosis of good cochlear reserve and the prognosis for improvement was favorable

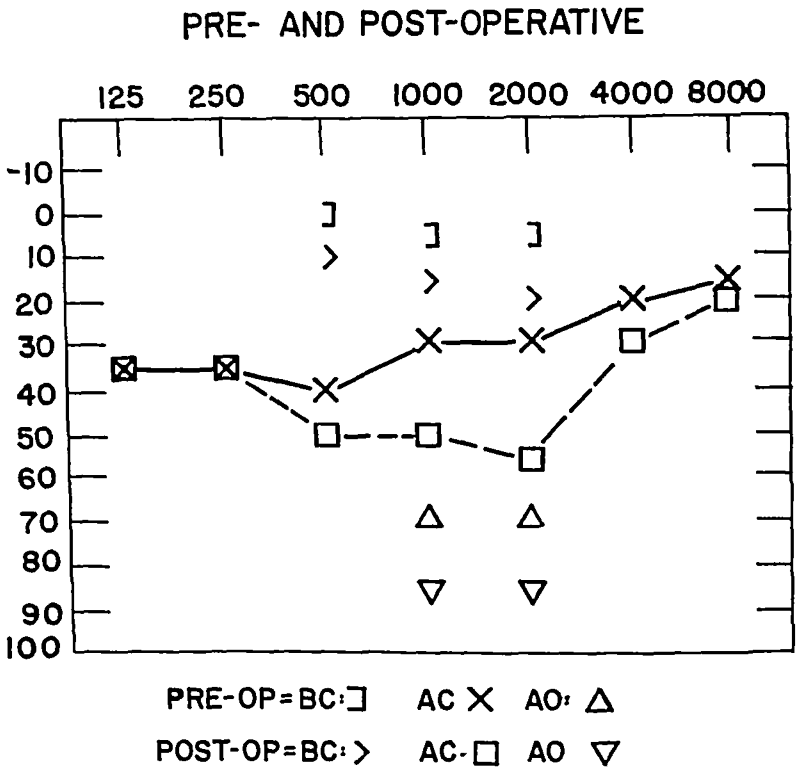
Post-operatively we find not only a decrease in air and bone sensitivity but, more significantly a lowering of the linear range of hearing by 15 db at 1000 cps and 10 db at 2000 cps These post-operative measurements were made four months after surgery and indicate a stable condition These findings were interpreted as showing the presence of mild



AUDIOMETRIC DATA

| FREQUENCY | 1000 | | | 2000 | | |
|---|---|---|---|---|---|---|
| TEST | PRE-OP | POST- | CHNG | PRE-OP | POST- | CHNG |
| AC | 50 | 45 | +5 | 45 | 35 | +10 |
| BC | 15 | 10 | +5 | 20 | 20 | 0 |
| AO | 45 | 40 | -5 | 35 | 35 | 0 |

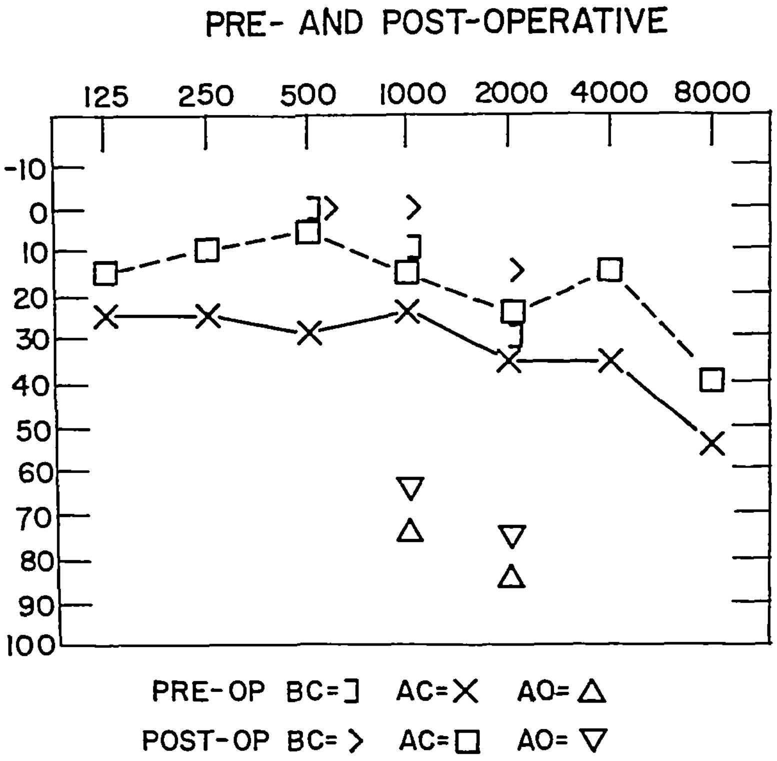
Fig 5 Results obtained in Case No 3



AUDIOMETRIC DATA

| FREQUENCY: | 1000 | | | 2000 | | |
|---|---|---|---|---|---|---|
| TEST | PRE-OP | POST- | CHNG | PRE-OP | POST- | CHNG |
| A C | 30 | 50 | -20 | 30 | 55 | -25 |
| B C | 5 | 15 | -10 | 5 | 20 | -15 |
| A O | 40 | 35 | -5 | 40 | 30 | -10 |

Fig 6 Results obtained in Case No 4



AUDIOMETRIC DATA

| FREQUENCY: | 1000 | | | 2000 | | |
|---|---|---|---|---|---|---|
| TEST | PRE-OP | POST- | CHNG | PRE-OP | POST- | CHNG |
| A.C | 25 | 15 | +10 | 35 | 25 | +10 |
| B C | 10 | 0 | +10 | 30 | 15 | +15 |
| A O | 50 | 50 | 0 | 50 | 50 | 0 |

Fig 7 Results obtained in Case No 5

cochlear involvement of a permanent nature most probably due to operative intervention however, the conductive component is still quite large, and the patient may still profit by fenestration surgery

*Case No 5* (see Fig 7) Female, age 41 Left stapes mobilization The pre-operative air conduction threshold curve shows a moderate loss in the ear in question but of a sufficient degree to lead the patient to seek medical treatment The bone-conduction threshold is within normal limits for 500 and 1000 cps, but bone sensitivity is only 5 db better than the air conduction threshold at 2000 cps On the basis of the audiogram alone an interpretation of poor cochlear reserve involving the high frequencies could easily have been made, however linearity measures at both 1000 and 2000 cps were found to be normal and mobilization of the stapes was carried out

Post operatively, the air-conduction curve is shifted upwards to fall within the normal range for most frequencies Bone conduction is improved by 10 db at 1000 cps and 15 db at 2000 cps The level of the harmonic threshold remains unchanged

This case illustrates at 2000 cps how fallacious it can be to depend entirely on the 'air bone gap" for a discriminating evaluation of cochlear reserve The pre-operative status of the cochlea for stimulation by a tone of 2000 cps was inaccurately shown by bone measurement, as attested by a normal and unchanging linear range of hearing at this frequency, as well as a significant improvement in bone sensitivity at 2000 cps after surgically reducing the degree of stapes ankylosis previously present

## DISCUSSION

The general observation that bone-conduction sensitivity is improved after fenestration or stapes-mobilization surgery in the majority of cases of otosclerosis is confirmed in this study It is safe to assume, on the basis of the evidence accumulated by the investigators dealing with this problem, that we cannot place complete reliance on the pre-operative bone-conduction threshold as an *accurate* indicator of true cochlear reserve in all of these patients We also cannot expect a post-operative improvement in bone sensitivity of a certain pre-determined amount in the majority of individual cases It seems reasonable to assume that the otosclerotic lesion, involving a reduction in movement of the footplate of the stapes, has a direct influence on the physiology of bone conduction, and that the removal of this condition, either by restoring stapes mobility or creating a labyrinthine fenestra, restores bone-conduction sensitivity to the level expected in the light of the existing cochlear function

In attempting to explain the reasons for the general improvement of bone conduction after surgical intervention, let us review briefly the theory of cochlear stimulation by osseous conduction and discuss the probable influence of otosclerotic pathology and surgery on the physiology of bone conduction.

The pathways of sound to the cochlea by bone conduction have been well defined by Guild,[23] and are familiar to all students of the hearing process. The osseous pathway, from the vibrator to the otic capsule directly through the bones of the skull, has been generally accepted as of much greater importance than the so-called osseo-tympanic route from the vibrator to the middle-ear cavity and thence to the round-window membrane.

The two modes of cochlear stimulation that have received maximum attention in the past are the translatory, or inertia, form of bone conduction, and the compressional mode. In translatory bone conduction, the contents of the cochlear capsule do not move in the same time relation with the bodily movement of the capsule itself. Because of the elastic qualities of the oval and round windows, the inertia of the cochlear fluids allows for a time lag in movement. Inertia opposing the vibratory force is also provided by the ossicular chain. When the labyrinthine capsule is placed into movement, the footplate of the stapes lags behind, due to the restraint on the stapes provided by the inertia of the ossicular chain. Thus, under these two conditions, the cochlear fluids are displaced relative to the capsular walls, providing concomitant displacement of the basilar membrane and resultant stimulation of the hair cells.

The compressional mode of bone conduction calls for periodic volume displacements of the cochlear fluids in direct relation to, and synchronous with, the periodic condensations and rarefactions of the stimulus sound. The theory implies that the entire labyrinthine capsule expands and contracts in response to stimulation, and that every portion of the capsular wall is vibrated with approximately the same force. A compression of the capsule would bulge out the round window due to fluid displacement, and a rarefaction would have the opposite influence on the membrane. In either case, resultant movements of the basilar membrane would produce neural stimulation.

The studies of Barany,[29] Bekésy[30] and Smith[17] all amplify the importance of the translational mode of stimulation. The compressional form is considered to be less significant and not affected to a great degree by stapes fixation.[17] Accepting this conclusion, we are led to the belief that in order to achieve adequate stimulation of the organ of Corti by bone-conducted sound, it is necessary to have at least two elastic membranes in the walls of the labyrinthine capsule in order to provide adequate mobility of the labyrinthine fluids with concomitant activation of neural impulses by hair-cell stimulation. When the impedance of the ossicular chain is increased by stapedial fixation due to otosclerosis, the normal translational mode of cochlear stimulation by bone-conduction is altered and, in the majority of cases, bone sensitivity is reduced. When normal mobility of the fluids is restored, either by restoration of stapedial vibration in the oval window or by the surgical provision of a new window in the horizontal semi-circular canal, an improvement in bone-conduction sensitivity is usually seen.

That certain changes in the status of the middle ear can influence the accuracy of bone sensitivity has also been borne out by studies involving conditions other than otosclerosis. Bárány[29] studied the effect of reduced middle-ear air pressure on bone-conduction sensitivity at 435 cps., and found that in the normal human ears examined, bone sensitivity was reduced approximately 10 db under this condition. It could be hypothesized that the reduced air pressure in the tympanic cavity lowered the normal quality of mobility of the round-window membrane. Recently, Palva and Ojala,[31] after testing a series of 42 ears with catarrhal or purulent otitis media, in some of which bone conduction was improved after myringotomy, aspiration and subsequent healing, concluded that in certain cases of conductive-type hearing loss, the initially lowered bone-conduction threshold "does not necessarily indicate a perceptive involvement, but may be due to impaired mobility of the oval and round window."

Technically, there should be little difference between the stapes mobilization or fenestration procedures in the inherent quantitative restoration of bone sensitivity. In the former technique, the original anatomic and physiological condition of the middle-ear structures are functionally restored In the latter operation, although the transformer action of the ossicular chain is no longer present, there still is a sufficient difference in the phase relationships of the round window and the fenestra to insure adequate fluid mobility, providing the tympanic flap adequately isolates the round-window membrane

As mentioned in the results of this study, it was found that there was a comparatively greater improvement in the mean air and bone thresholds in those ears that had undergone fenestration surgery Except for the mean bone-conduction threshold at 2000 cps, the original extent of hearing loss was greater, on the average, in the "fenestrated" group, and yet at both frequencies post-operatively, there was a greater improvement in mean threshold in the latter group These observations, though broad and inconclusive, lead one to speculate whether the formation of a new window, with relatively small inherent impedance characteristics as compared to the status of the normal oval window, produces better opportunities for more normal fluid mobility The answer to this problem must, of course, await further exploration

One important advantage of the aural-harmonic test, both physiologically and clinically, is its relatively stable characteristic under conditions of middle-ear pathology or surgical intervention Although normal bone-conduction sensitivity depends to some extent on the relative normality of the middle ear, the process of recording amplitude distortion by the exploring-tone technique is not affected by any malfunction of the middle-ear mechanism Normal measurements of linearity may be recorded even when the ossicular chain, down to the footplate of the stapes, is removed[32] Thus, the critical factors of fluid mobility and general loss in air-conduction sensitivity affecting bone conduction have relatively no effect on distortion measurements using the exploring-tone technique The fact that a quantitative threshold may be obtained by the aural-harmonic procedure connotes the possibility that a quantitative evaluation of cochlear function may be determined. It is apparent that such a measure would be of great value in determining the efficacy of surgery, and it may have some importance in discerning the relative advantages of one operative technique over another in an individual case; however, until a much greater pathological sample is studied, we must be satisfied with the present use of the procedure in diagnostically delineating cochlear involvement.

In studying and endeavoring to interpret the means presented in Table IV, it must be emphasized that in the realm of operative prognosis in the patient with otosclerotic deafness we are concerned with discrete and individual anatomic, physiological and pathological problems that may vary remarkably with each patient encountered. Although the application of certain group measurements of auditory function to an individual case may be helpful in pointing out a general trend, they cannot be relied upon implicitly to give an accurate picture of future measurements. This is especially so after operative intervention with all of the concomitant parameters of technique involved, and unknown resultant changes in the physiological conduction of sound by the middle-ear mechanism in the case of the stapes-mobilization procedure. For example, in only one ear in this study (Case 5) were pre-operative corrections of the bone-conduction curve, as determined by the "otosclerotic notch" principle, confirmed post-operatively. The primary importance of this principle is that it has brought to the attention of otologists the fact that a pre-operative bone-conduction audiogram obtained in an ear with otosclerosis is a relatively inaccurate indication of the actual capacity of the organ of Corti to be stimulated by sound conducted through the osseous pathway.

In being critical of group results obtained by bone-conduction testing, it would also seem consistent to be equally critical of group means obtained by the aural-harmonic test; however, it must be emphasized that a different physiological principle is involved in measuring cochlear distortion. We need not be concerned with the possible changes in the anatomical or physiological condition of the middle ear since any changes, even of a gross nature, have an insignificant effect on the measurement of cochlear distortion in terms of sensation level The studies of Wever, Bray, and Lawrence on animals,[17, 32, 33, 34] and the results obtained in human ears such as tested in this study, substantiate this conclusion

One main observation is emphasized In the patients tested in this study, it was found that there is less change in the mean harmonic threshold post-operatively than in the mean bone-conduction threshold, and that in terms of accuracy and stability it is felt that more reliance can be placed on the aural-harmonic test as a direct measure of cochlear function This observation seems of value in obtaining more consistent pre-operative measures of cochlear function in cases of clinical otosclerosis, however, of far greater importance, we feel, are the observations and interpretations made in the individual case with respect to variations and consistencies in the two techniques

In conclusion, it seems somewhat fallacious in developing a prognosis for either fenestration or mobilization surgery to be satisfied with the principle of "closing the air-bone gap" as determined by pre-operative examination It is certainly true that successful operative intervention will, in most cases, bring air-conduction sensitivity close to the pre-operative bone threshold, however, it is our belief that the otologic surgeon still has the responsibility of determining the condition of cochlear function as accurately as possible, before attempting to predict the effects of surgery in the individual case The comparison of air- and bone-conduction sensitivity alone is not adequate in most cases Qualitative judgments can be made with other tests, such as loudness-balance recruitment techniques, the discrimination score for speech, etc Our experience with the aural-harmonic test as one of a battery of such procedures has been very helpful The use of this technique as an actual quantitative measure of cochlear function has interesting potentialities, and the accumulation of data in a significantly large sample of otosclerotic ears is now being carried out in an attempt to determine the merit of this possibility

## SUMMARY

Pertinent literature is reviewed, citing evidence for the post-operative improvement of bone-conduction sensitivity in the ear with a hearing loss due to clinical otosclerosis It is emphasized that in most cases the measurement of bone-conduction thresholds in the ear with otosclerotic pathology may give an inaccurate picture of the true capability of the organ of Corti to respond to osseous stimulation

The theory behind the aural-harmonic (aural-overload) test as a measure of cochlear function is briefly reviewed, and previous studies on human ears are discussed In order to compare the relative stability of the two techniques (bone-conduction and harmonic measurements) in the evaluation of cochlear reserve, air-conduction, bone-conduction and aural-harmonic thresholds were obtained before and after either stapes mobilization or fenestration surgery in 19 patients with clinical otosclerosis A total of 20 ears was examined

It was found that at 1000 cps there was a mean improvement of 22 db for air conduction, 10 db by bone conduction, and a mean change in the linear range of hearing of only 3 db In the ears tested completely at 2000 cps, a mean improvement of 19 db in the air-conduction threshold, a change of 9 db in bone conduction, and no mean change in the harmonic threshold was found, thus, in this sample, the aural-harmonic test was found to be a more stable measure than the bone-conduction threshold Five illustrative cases are presented and discussed

The influences of stapes ankylosis and surgical intervention on the physiology of bone conduction are discussed It is concluded that more reliance must be placed on audiometric techniques that are not influenced by anatomic and physiological changes in the middle ear in attempting to judge the status of the organ of Corti adequately The aural-harmonic test, as one of a battery of such techniques, is proposed as an adjunct to a complete diagnostic evaluation of the patient with clinical otosclerosis

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# THE CONTROL OF ITCHING OF THE EXTERNAL EAR WITH SANDOSTENE®

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A number of investigators have reported the effective use of Sandostene® in relieving pruritis associated with a variety of allergic dermatologic conditions This is a first report of the use of this preparation exclusively for the relief of pruritis associated with external ear conditions We have evaluated Sandostene® in 147 cases of itching associated with pathology of the external ear The control of itching has been dramatic, and the incidence of side effects has been minimal

Sandostene® chemically is 1-Methyl-4-amino-$N^1$-phenyl-$N^1$-($2^1$-thenyl) piperidine tartrate The drug is commercially available as an enteric coated tablet, each tablet containing 25 milligrams of the active substance Pharmacologically, Sandostene® has been shown to exhibit a variety of effects which would influence allergic processes Its three physiologic actions, antipermeability, anticholonergic action and histamine antagonism make it ideally suited for the treatment of pruritis, as well as for controlling allergic responses

The control of itching in the external ear is a most important therapeutic problem The patient traumatizes the skin of his ear canal in an attempt to relieve the symptoms of itching, and in this way opens the pathway for infection Scratching is an attempt to replace the burning, itching feeling with a less unpleasant sharper sticking but more painful sensation The painful sticking sensation replaces the burning itching sensation even though itching fibers are still being stimulated As soon as we stop scratching, the painful sensations of short duration cease, and the itching sensation again becomes pronounced We then try to replace it with

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sticking pain by scratching, and the more we scratch the more after discharge of unpleasant itch occurs The scratching traumatizes the ear canal, and in this way secondary infection can begin

## MATERIAL AND METHOD

This study was based on observations made in 147 patients seen in private practice over a period of approximately one year All complained of various degrees of itching associated with pathology of the external ear In some cases the pathology was primary in the external ear, and in a number of cases the pathology was secondary to middle ear infections

This study was designed to evaluate the symptomatic relief of itching and to determine whether the relief of itching influenced the length of time necessary to control the pathologic condition We were interested in determining the most effective dosage of Sandostene® for controlling itching, and we were further interested in determining whether we could prevent external ear infections which were due to scratching the skin of the ear canal in an attempt to relieve itching

## DOSAGE

Sandostene® in 25 mm tablets, coated and uncoated, were available at various times during our study Our dosage routine varied and was influenced by the response of the patient In acute conditions where there was infection and marked itching, we started the patient on 50 mgm Sandostene®, four times a day When there was no relief with the first 24 hours, we instructed the patient to double the dosage so that the total dosage would reach 400 mgm per day In instances where there were side effects of drowsiness or nausea we instructed the patient to drop the dosage to 25 mgm four times a day

After a 72-hour-dosage schedule such as outlined above, the patients were instructed to cut the dosage of Sandostene® to either 25 or 50 mgm as necessary for itching In a small number of cases where the medication was used for children or in adults who could not easily swallow tablets, Sandostene®

syrup was used There seemed to be no difference in the therapeutic effectiveness of the medication when used in the form of syrup

Patients reported relief from itching in 20 to 30 minutes when Sandostene® was used The duration of effect was very difficult to evaluate, as the medication was taken routinely at four hour intervals in acute cases When the patients were on the PRN dosage schedule, they experienced relief from itching for as long as 24 to 48 hours Obviously, this did not indicate a prolonged Sandostene® effect, but rather that itching did not recur

TABLE I

| Diagnosis | No of Patients | Dosage | | Other Treatment | Relief of Itching Within 24 Hours | | | Side Effects | |
|---|---|---|---|---|---|---|---|---|---|
| | | 200mg per day | Other | | Comp | Part | None | Dry mouth | Nausea |
| Diffuse External Otitis | 69 | 50 | 19 | 51 | 60 | 6 | 3 | 3 | 4 |
| Eczematoid Ext Otitis | 33 | 26 | 7 | 24 | 27 | 3 | 3 | 2 | 4 |
| Secondary External Otitis | 9 | 8 | 1 | 9 | 2 | 4 | 3 | 1 | 0 |
| Postoperative | 6 | 5 | 1 | 6 | 0 | 3 | 3 | 1 | 0 |
| Perforation | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Chronic Otitis Media | 2 | 2 | 0 | 2 | 1 | 1 | 0 | 0 | 0 |
| Otomycosis | 6 | 4 | 2 | 6 | 0 | 0 | 0 | 0 | 0 |
| External Canal Pruritis (No Specific Etiology) | 6 | 6 | 0 | 0 | 4 | 2 | 0 | 0 | 0 |
| Circumscribed External Otitis | 24 | 19 | 5 | 15 | 9 | 9 | 6 | 1 | 0 |

## RESULTS

The summary of findings are indicated in Table I The summary indicates that the majority of cases treated were either diffuse external otitis or eczematoid external otitis There was relief of itching in approximately 90 per cent of these cases within 48 hours The majority of these cases were using other local and systemic medications to control the diffuse infection In our experience only 30 per cent of patients are relieved of itching with the usual general or local therapeutic agents

In the classifications of otomycosis and external otitis secondary to middle ear pathology the relief of pruritis was prompt and complete, regardless of the causative organism

Of special interest to us were the cases in the category of external canal pruritis with no specific etiology Here again there was complete relief of itching, this therapeutic response was not reproducible with any other medication

The category in which the poorest results were obtained was in the circumscribed external otitis Relief of itching was observed in only about 50 per cent of the cases, and this closely approximated the results obtained with other medications

## SAFETY

The incidence of side effects was approximately 10 per cent Nausea and marked dryness of the mouth were experienced, but neither were of particular consequence as they were relieved by cessation of the use of the medication In all but two cases the patients were able to continue the use of the drug, as the side effects were so minimal in nature In only two cases did the patients volunteer the symptom of nausea or dryness of the mouth In the other 13 cases we had to elicit the symptom by direct questioning of the patients

## CONCLUSION

In our series of 147 cases external canal pathology we have found that Sandostene® is an excellent therapeutic tool for the subjective relief of itching It provided relief of itching in 90 per cent of the cases studied and is, therefore, an excellent adjunct medication in the treatment of external otitis It is our belief that one of the primary factors in the pathophysiology of external canal infections, such as experienced in more humid climates, and infections associated with swimming, is that the patient responds to the itching of the ear canal by scratching The trauma inflicted opens pathways of infection that were not present, and an ear canal infection ensues

We have found that the use of Sandostene® for symptomatic relief of itching is extremely effective in preventing ear infections Individuals who have considered themselves as having chronic ear infections have been amazed to find that their flareups were few and far between when Sandostene® was used for the symptomatic control of itching Preventing scratching and subsequent trauma of the skin of the ear canal maintains the pH of the skin of the ear canal and thus prevents the development of conditions conducive to infection

## SUMMARY

*1* 90 per cent of the patients treated obtained relief of pruritis, within the first 24 hours of Sandostene®, therapy

*2* We have found that 50 mgm of Sandostene®, four times daily, is the preferred dosage for the first 72 hours, after that time dosage is altered to either 25 or 50 mgm taken as necessary for itching

*3* We have further found that children can tolerate similar dosages either in the compressed tablet form or in the form of Sandostene® syrup

*4* Ten per cent of cases experienced side effects of either nausea or extremely dry mouth, but in all cases the side effects responded either to lowering the dosage or discontinuing the drug

We have found no essential relationship between the cause of the external auditory pruritis and the ability of Sandostene® to provide relief of itching We feel very strongly that Sandostene® is an excellent agent to be used for its antipruritic effect in external auditory canal pathology

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*Sandostene® supplied by Sandoz Pharmaceuticals Division of Sandoz Chemical Works Inc. Route 10 Hanover N J

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## COURSE IN RECONSTRUCTIVE NASAL SURGERY

The Department of Otolaryngology, University of Cincinnati College of Medicine, announces a Course in Reconstructive Surgery of the Nasal Septum and External Pyramid The course will be under the direction of Dr Maurice H Cottle, Professor of Otolaryngology, Chicago Medical School, and a selected faculty, in association with the American Rhinologic Society, April 12 through April 19, 1958 Class membership limited Tuition $350 00 Please apply to Dr Henry M Goodyear, Professor of Otolaryngology, College of Medicine, Eden and Bethesda Avenues, Cincinnati 19, Ohio

# THE 11TH CONGRESS OF THE INTERNATIONAL ASSOCIATION OF LOGOPEDICS AND PHONIATRICS

The 11th Congress of the International Association of Logopedics and Phoniatrics will take place in London, August 17-22, 1959 The following official reports will be presented The Inheritance of Voice and Speech Disorders, Prof R Luchsinger, M D , Zurich, Defects of Articulation, Muriel Morley, B Sc , F C S T , Newcastle, The Physiology and Pathology of the Soft Palate, Prof Lucio Croatto, M D , Padua The official languages of the Conference will be English, French, and German

Those working in the field of Speech and Voice Therapy and all who are interested in this specialty are invited to attend and to submit papers

If intending to be present, whether submitting a paper or not, please inform the Congress Secretary at the earliest possible date

Papers are invited on subjects relevant to the three main reports or any other aspect of speech and voice Only one contribution will be accepted from any one member of the Congress and this must not have been previously published The Committee reserves the right to select papers Papers should be restricted to 15 minutes in length, demonstrations to 10 minutes In special cases 20 minutes may be allowed for a paper of great importance but only if application is made at the time of submitting the title Should a group of four or more people wish to present a symposium or a prepared discussion on a theme, consideration will be given to allocating up to one hour for such a contribution

Titles must be received by September, 1958 Summaries must be received not later than November 15th, 1958

All communications are to be sent to Peggy Carter, L C S T , 46 Canonbury Square, London, N 1

# SUBCOMMITTEE ON HEARING IN CHILDREN

The American Academy of Ophthalmology and Otolaryngology, through its Subcommittee on Hearing in Children of the Committee on Conservation of Hearing, has been conducting a long-term nationwide study of problems relating to the conservation of hearing in children The specific aims are to develop the most efficient case-finding methods and to use these methods in estimating the magnitude of the problem in the country, to study state laws and review current practices and facilities for rehabilitation of hearing impaired children, to help develop methods for medical and surgical rehabilitation standards, and ultimately to use the Subcommittee findings in assisting professional workers to improve and enhance programs in hearing loss

In the second year of operations, a full-time Executive Director has been engaged, and offices established at the Graduate School of Public Health, University of Pittsburgh An initial study is being conducted in Pittsburgh to identify early medical signs and symptoms which may indicate danger of hearing impairment, to measure the psychological, social and other effects of such impairment and to develop efficient and economical methods for the testing of hearing in children The Pittsburgh study is a cooperative effort among the following The Subcommittee on Hearing in Children, the Graduate School of Public Health and the School of Medicine of the University of Pittsburgh, the Pittsburgh Board of Public Education, and the Allegheny County Department of Health.

The members of the Subcommittee on Hearing in Children are Dr John E Bordley, Baltimore, Dr Victor Goodhill, Los Angeles, Dr Hollie E McHugh, Montreal, Dr S Richard Silverman, St Louis, and Dr Raymond E Jordan, (Chairman) Pittsburgh. An advisory committee of consultants from the University of Pittsburgh includes Dr Samuel M Wishik, Dr Leo G Doerfler, and Dr Isidore Altman. Grants from the United States Children's Bureau through the Pennsylvania Department of Health and from the National Institutes of Health are providing financial support

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SPECIAL ISSUE OF

THE

LARYNGOSCOPE.

VOL LXVIII MARCH, 1958 No 3

# PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON AUDIOLOGY

May 13 through 16, 1957

St Louis, Missouri

## FOREWORD

In connection with the official Midwest tours scheduled for the Sixth International Congress of Otolaryngology, held in Washington, May 5-10, 1957, one of the Organizing Committee, (S R Silverman) was asked by numerous individuals, both in the United States and abroad, to organize an International Conference on Audiology in St Louis immediately after the Congress The chief purpose of this Conference would be to create a situation where laboratory investigators could share their views and findings with an interested and sophisticated clinical audience The themes explored by the Conference were the Assessment of Auditory Function, the Physiology of Audition, and the Relation of Hearing Loss to Noise Exposure

The goals of the Conference are summarized in the following extract from the welcoming address of the Chairman to the members of the Conference

*To Participants in the International Conference on Audiology—A Cordial Welcome to St Louis*

From many lands a common interest in hearing and deafness brings us together It is true that our primary interests may vary We may be concerned with the structure of the auditory system or with its function, or with the diseases that afflict it, or with the impairment in social efficiency brought about by hearing loss Some of us work in the laboratory, others in the clinic and still others in the classroom, but the rapidity with which our knowledge, nurtured by many sources, is increasing, suggests clearly and emphatically that we create situations, such as this Conference, where we may share information that enriches our understanding and stimulates our activity If the Conference contributes in some small measure to the enthusiasm and the wisdom with which you pursue your tasks in the field of hearing and deafness, those responsible for its organization will have been richly rewarded

* * *

Of the actual scientific and professional membership of the Conference, fields of interest were represented as follows Audiology, including teachers of the deaf and speech pathologists, 42 per cent, Otolaryngology, 39 per cent, Psychology, Engineering and Physiology, 15 per cent, and Commercial, including makers of electroacoustic instruments, 4 per cent

The editors of the Proceedings of the International Conference on Audiology were S Richard Silverman, Chairman of the Conference, Ira J Hirsh, Program Chairman, and Shirley K Hirsh, Conference Secretary

The Conference acknowledges with appreciation its indebtedness to the National Science Foundation of the United States Government for providing the major portion of its expenses through a grant to the Central Institute for the Deaf

The Conference expresses its gratitude to the members of the staffs and friends of the Central Institute for the Deaf, and the Department of Otolaryngology of Washington University for assistance in arrangements, and to the School of Medicine of Washington University for provision of meeting rooms

# PROGRAM OF TECHNICAL SESSIONS

## Tuesday Morning, May 14

## WELCOME

Presiding S RICHARD SILVERMAN Director Central Institute for the Deaf, Chairman International Conference on Audiology

THE HONORABLE RAYMOND R TUCKER Mayor of the City of St. Louis

ETHAN A H SHEPLEY Chancellor Washington University

## SESSION A—CONTRIBUTED PAPERS

Chairman IRA J HIRSH Head, Psychology Laboratory, Central Institute for the Deaf, St Louis Mo

1 **Some Similarities Between Hearing and Seeing**

S S STEVENS Professor of Psychology, Director of Psycho Acoustic Laboratory, Harvard University, Cambridge, Mass 508

2 ***An Attempted Synthesis of Psycho Acoustic Test Data in the Audiological Clinic***

J DONALD HARRIS Head, Sound Branch Medical Research Laboratory, U S Naval Submarine Base New London Conn 527

3 **Triplet Testing and Training—An Approach to Band Discrimination and its Monaural or Binaural Summation**

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4 **Relation of the Lombard Effect to Speech Production**

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5 **A Comparison of Picture Response and Hand Raising Techniques in Pure Tone Audiometry with Young Children**

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6 **Progress in the Comparison of Sleep EEG Audiometry with Standard Audiometry**

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WILLIAM G HARDY Director Hearing and Speech Center The Johns Hopkins Hospital Baltimore Md

HELMER R MYKLEBUST Professor of Audiology Northwestern University Evanston Ill

LOUISE TRUNQUE Chief Audiometric Department University of Lyons France

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Open House—Central Institute for the Deaf Clinics and Research Building

Demonstration of classroom procedures with deaf hard-of hearing and aphasic children and also of testing and teaching techniques for children and adults

Research laboratories and shops were open for inspection and demonstration

Exhibitions included Central Institute Library and the Goldstein Collection of hearing aids

A film by Georg von Békésy was shown at 8 30 and 9 30 P M

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# PROGRAM OF TECHNICAL SESSIONS

## Tuesday Morning, May 14

## WELCOME

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The Honorable Raymond R Tucker Mayor of the City of St Louis

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C A Amesur Member National Advisory Council for the Education of the Handicapped Bombay India and
C Satyanarayana Professor of E N T Diseases Stanley Medical College Madras India 677

## NATIONAL ORGANIZING COMMITTEE

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Hallowell Davis Central Institute for the Deaf and Washington University School of Medicine

Harvey Fletcher, Brigham Young University

William G Hardy Johns Hopkins Hospital

John Lindsay University of Chicago

Philip E Meltzer Tufts University Medical School

S S Stevens Harvard University

*Program Chairman*

Ira J Hirsh Central Institute for the Deaf and Washington University

*Conference Secretary*

Mrs Shirley K Hirsh

## Thursday Afternoon, May 16

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*Conference Secretary*

Mrs Shirley K Hirsh

## TUESDAY AFTERNOON SESSION,

May 14, 1957

## THE ASSESSMENT OF AUDITORY FUNCTION

## I HEARING IN CHILDREN—PANEL DISCUSSION

| | |
|---|---|
| CHAIRMAN | S Richard Silverman, Director, Central Institute for the Deaf, St Louis, Mo |
| PANEL | Robert Goldstein, Research Associate, Central Institute for the Deaf, St Louis, Mo<br>William G Hardy, Director, Hearing and Speech Center, Johns Hopkins Hospital, Baltimore, Md<br>Helmer R Myklebust, Professor of Audiology, Northwestern University, Evanston, Ill<br>Louise Trenque, Chief, Audiometric Department, University of Lyons, France |

DR SILVERMAN The essayists were asked three questions in preparation for this discussion These questions are as follows

One What goals, particularly with reference to educational recommendations, can be set for the testing of the hearing of young children?

Two What evidence is there that results of hearing tests on young children can yield information about the pathology of auditory and other disorders?

Three What particular testing techniques have you found to be most successful in yielding answers to either or both of the first two questions?

One, then, is a matter of goals, two, is a matter of evidence, and three, what do you actually do when you assess the hearing of a young child?

Dr Hardy, will you lead off?

DR WILLIAM G HARDY Any one of these topics is worth an hour's discussion, so I am going to move through my material rather rapidly and hope that we may be able to pick up some of the more important indicators as the discussion proceeds

There are at least six objectives which we feel (I am talking as a representative of our departmental group) might well be kept in mind First, to ascertain the status and needs of the child regarding possible medical and surgical treatment This aspect of a problem is too often overlooked, and it must not be, particularly in dealing with younger children Incidentally, need we remind ourselves that we are not talking about a refined, preselected diagnostic group, all of whose problems are solely centered in hearing? The children we meet at the age of one, two, or three years, are referred because they do not talk, because they have not learned language, because they have not developed normally The reasons for these defects are manifold, involving much more than the possibility of impaired hearing

Second, to measure or estimate the child's potential for learning language and verbal communication Fundamental to this, perhaps, is the potential of the auditory mechanism, but by no manner of means should the inquiry exclude other sensory modes of learning

Third, to differentiate among several possible reasons for the lack of development of language and speech In terms of differential diagnosis, this may involve a tremendously complex inquiry We find that oftentimes this involves a closely integrated task among five or six of our major departments in the hospital

Fourth, to measure residual hearing as a basis for psychoacoustic development

Fifth, to try to learn the nature of the hearing impairment for what this information can contribute in terms of special needs in training Many of these objectives overlap, of course, and any effort to clarify reflects some of the comments in another paper given this morning our need to clarify our language in terms of what we mean by *hearing* Is hearing an "adequate response," or is it a "significant response" to a measured or variable set of stimuli, or is it simply "a response." Our references must be clarified, for in his experience with differential diagnosis one comes face to face very early with the realization that he inevitably is dealing with much more than the function of the auditory system. The auditory system presents only one kind of information to the mind. As one watches more and more of these tiny children who are apt to give sporadic, variable, inconsistent responses to sound, one is forced to wonder what this auditory experience is like to the child. How can it be described in a single concept? Suppose that a given child has some disorder or lack of development at the level of difficulty in brief memory-span. This might be directly, or only remotely, connected with an auditory deficit, yet what would the world of sound-stimulus, particularly speech-stimulus, be like to a little fellow who needs 75 milliseconds, instead of five milliseconds, in order to monitor his own vocal output? These are points of differentiation on which we have as yet barely begun to touch. The modes of trying to apprehend, measure, and describe this sort of deficit are still in their infancy. Related, without doubt, are variables in pitch-perception, perhaps at the cortical or immediately subcortical levels of the auditory mechanism.

Sixth, to develop information relative to the nature of the hearing mind in terms of whatever effects of stimulus and inhibition can be observed in the responses of the child. A child must go through a period of readiness to listen before he can progress very far in the development of language and speech. This is, in part, a matter of the mind's meanings, of the conditioning of behavior to react or not to react to a particular sensory modality-like hearing. It is probably at this stage of clinical judgment that one must differentiate between the fact of a child's response to sound, and a possible meaning of this experience to him. Here we are at the level of cortical integration, and there simply is not time to discuss the many possible ramifications.

I believe that all of these become extremely important objectives in an effort to refine hearing tests with reference to educational recommendations.

Dr Hirsh, translating for Dr Louise Trenque[*]

DR IRA J HIRSH There are four major objectives one, is the child deaf? In the young child, in the majority of cases, the problem consists of establishing primarily whether or not deafness exists The fact that the child is helped most by the specialist from about 18 months on is because the language either does not appear or because the language is not developed normally Frequently the parents suspect the existence of deafness, but it is still necessary to confirm it

The second objective is to quantify the extent of the deafness Is deafness complete? Are there existing auditory residuals that might be used by the child in hearing speech efficiently? The value of these auditory residuals is most important if it appears that the child can hear speech partially, or possibly better with a hearing aid By using these residuals, for example, in perceiving some of the phonemes or the melody of the sentence, one can hope to rehabilitate the child completely Thanks to appropriate education this child can become capable of speaking with a voice that is comprehensible to all, capable of understanding what is said to him, and capable of acquiring even abstract thought at a level consistent with children of the same intellectual capacity and environment

Third, is deafness the only deficiency in the child? In our opinion it is of prognostic importance to ascertain whether the deafness is the only trouble, or whether there are others such as physical characteristics, deficiency in intelligence, difficulty in memorization and comprehension, superimposed upon the auditory deficit A large proportion of children in whom we have found audiometric curves of between 60 and 80 decibels, in whom, because of these auditory residuals, we have placed much hope, have disappointed us following the examinations In the course of their education, we were confronted with various difficulties, among the most severe of which have been dyslexia, dysgraphia, emotional instability, disorders in the development of learning, comprehension and intelligence, and those factors that interfere with the development of language beside those involved in the hearing

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[*] Dr Louise Trenque was unable to attend the Conference because of illness She sent a manuscript however through one of the conferees which was received about an hour before the panel discussion was to begin Dr Hirsh's translation of her answers to the questions posed by the Chairman was therefore almost in the nature of a simultaneous translation There are many omissions and undoubtedly some errors but the Editors consider that at least her general point of view is fairly represented

Finally, as the fourth objective, Dr Trenque lists the study of the origin of deafness This study has both therapeutic and prophylactic aims and can aid in our prognostic judgments therapy in cases of rhinogenic deafness, prophylaxis, for example, in the RH factor or syphilis, prognosis, as in cases where we observe obstetrical trauma

DR ROBERT GOLDSTEIN Because our concern on this panel is primarily educational, we will consider the results of hearing tests as one basis for making educational recommendations My discussion today is restricted, first, to those auditory problems whose severity requires that education be handled, at least for a time, in special schools or special classes, two, to the very young children who have not yet had any individual or classroom instruction, from which we might ordinarily derive significant diagnostic clues, and third, to those children whose auditory disorder is not secondary to severe emotional disturbance or to mental deficiency

Our goals should depend primarily on what we know of the kinds of educational methods that have been used successfully on children with various auditory disorders My discussion is further restricted to what is known in general about the success of various approaches to oral education, acknowledging our desire to accord every child the opportunity for developing oral communication

Considering the present state of knowledge about the education of children with auditory disorders, I believe that we should find out from our hearing tests whether a child's auditory disorder results primarily from a serious reduction in auditory sensitivity or primarily from a defect in auditory perception and linguistic development

The education of hard-of-hearing children and deaf children, that is, children with varying losses of auditory sensitivity, although not uniform or simple, has been carried on with appreciable success, and has been described in some detail By comparison, we know very little about the success in educating children whose disorder can be described as defective auditory perception, or as the inability to produce and/or to understand language There are scattered reports of success with certain educational approaches, but there are no comprehensive reports in which an educational method has been described, the children taught by this method clearly defined and enumerated, and careful assessment of results presented I feel competent, therefore, to refer only to our own experience for my contribution to the evaluation of this question

We have classified a large number of our children as aphasic We are aware of the controversies around this term, and for now, at least, we are not restricting ourselves to any particular definition of it These children we call aphasic have as their main problem the inability to develop language, presumably because of some dysfunction of the central nervous system This is not a homogeneous group, either from the standpoint of organic problems or from the standpoint of ability to use language, nevertheless, we use the same educational method with all of these children and achieve varying but considerable success with them We make no attempt to develop a different procedure for each sub-classification of the aphasic group but modify certain aspects of our overall procedure when the situation calls for it

If the findings on a particular child are inconsistent and do not clearly identify a child as deaf or aphasic, we generally recommend that this child be taught according to the system we use with aphasic children We have found from experience that we do little educational harm to children who eventually prove to be simply deaf, by teaching them according to our system for aphasic children On the other hand, we have seen much educational time lost on aphasic children who, because of uncertainty in diagnosis, were taught by methods conventionally used with deaf children

On the basis, then, of our experience in educating children with auditory disorders, we try to answer this major question when we are examining a young child is his inability to communicate primarily the result of a reduction in auditory sensitivity or is it primarily the result of a defect in auditory perception or in the ability to produce or to understand language?

DR SILVERMAN We turn now to our second question What evidence is there that results of hearing tests on young children can yield information about the pathology of auditory or other disorders?

DR WILLIAM G HARDY I seem to have ten points listed for this topic First, it is clear that with the use of a wide variety of techniques (and each of us selects the particular pattern that he finds most rewarding) the function of the peripheral hearing mechanism—the end-organ—can be measured There is a matter of definition here that is apt to make discussion confusing Where does the peripheral mechanism stop and the central mechanism begin? My group has given a great deal of thought to this question, it is not simple Let us assume that the central mechanism begins at the level of the brain stem where one is dealing with audition as a neurally bilateral sequence of events, and that the ganglion-cell structure may be considered in the peripheral mechanism I realize there may be something wrong with this, for we are including the first neural synapse in the end-organ The geography of anatomy is perhaps not quite so important, however, as an agreement on reference In terms of these distinctions between peripheral and central, I believe we have a right to say that there is incontrovertible evidence that the function of the peripheral mechanism can be measured quite adequately

From here on, a clear differentiation of possible pathology is in large part speculative Fortunately, in this regard, one has the opportunity (which he must learn to take) of follow-up, or reassessment, as Dr Goldstein just indicated, to take advantage of comments and observations from the teacher, derived from the child's day-to-day performance A child is exposed to an ordered process of training in class, and it helps a great deal to know what a trained, thoughtful observer sees the child do This kind of information is not available for a two-year-old, of course, but with ever younger age-ranges being admitted these days to special educational situations, the evidence begins to mount up by the time a child is six or seven years old.

For many years in our department we have been particularly interested in the use and misuse of galvanic audiometry. We find that there are three kinds of patterns relating to the situation *1* the ease and speed of conditioning, *2* the latency of the response, *3* various details of timing involved in the test-picture. With relatively few exceptions, when one is dealing with damage to the peripheral mechanism, conditioning is easy, ready, and consistent. Latency of response is usually within half a second. The requirement of reinforcement may vary considerably. So, too, does the nature of the signal. Some children respond better to a steady-state tone, some better to a tone pulsed at a frequency of three or four per second. With the children whose primary problem turns out to be a language disorder, difficulty in integrating and putting to meaningful use the information presented through the auditory system, the same general patterns exist but with much extension of time. It takes longer for these children to be conditioned, and there may be extreme variations in latency of response. With the other large group of children who seem to have a central auditory problem, perhaps at the level of the interbrain or the thalamic loops, I doubt that the majority can ever be clearly conditioned. One may see responses, many of them, but they do not follow a pattern. There is much variety, too, in terms of latency and the details of extinction. This is perhaps relatable to the sort of thing currently being demonstrated in clinical psychology as more and more refinements of perceptive modes are studied in older children, some of these are relatable to various signs and symptoms of possible brain-damage, some are not. Psychologists use the term *variability* to describe many of the sensory inter-relations of the brain-damaged child, and it is felt that this is a good functional description of some of these central auditory problems. The signal, and the information derivable from it, changes, shifts. This is inconsistency from the point of view of the tester, variability from the point of view of the subject One wonders what the world of sound is like under these circumstances

When this discussion is finished we can probably all agree that the only really good test of the entire range of hearing, listening and understanding, the reflexes of the auditory mechanism and the integration of the cortical system, is a speech hearing test, but this, of course, remains beyond reach when one is dealing with small children, unless a particular child has developed some language and some useful speech

Back again to the auditory system, there are many interesting observations to be made relative both to loudness and pitch, the two psychological parameters of auditory sensitivity In our observations—and one doubts that the caseload we see is unusual—we find that among the children who offer clear evidence of profound auditory involvement, so much that they cannot possibly learn without the very best of special education, seven out of ten have something more than peripheral auditory lesions In reference here is the preschool-age group Approximately seven out of ten give evidence that their auditory difficulties lie somewhere in the brain stem or interbrain, in the thalamic structures, or in some aspect of cortical relationships

Dr Derbyshire made reference to a kind of "auditory hiatus" in some of these children We have had similar experiences Time and time again, we have tried to condition with a 90-decibel tone without success Then we shift to a 25-decibel tone and immediately get responses Sometimes, after a child begins to respond galvanically, one runs into a gap of perhaps 40 decibels, there are sporadic responses to various tones somewhere near the range of normal threshold acuity, but it requires a signal of 40 or so decibels above this level in order to achieve a consistent pattern of responses This almost forces one to think of some of the auditory problems commonly seen in a child with Rh athetosis Dr Goodhill and others have demonstrated by histopathologic evidence that at least in some of these children the damage may well lie at the level of the auditory nuclei in the brain stem We have examined many such problems, and find that with few exceptions they want much more loudness via a hearing aid or other amplification than does a child or an adult with a comparable pure-tone curve representing a peripheral problem

Some years ago, it became apparent that once there was good evidence of responses in the region of threshold acuity (we are still discussing galvanic skin resistance audiometry), it was profitable to observe reactions to a five- or six-octave pitch-swing at levels well above threshold Some children respond to this stimulus, some do not One cannot pretend to know the details of what this means Where there is a consistent reaction to this changing acoustic event, however, one may assume that it represents an on-going, different event to the child This capacity, we have observed, is commonly not present in children who prove to have extreme central auditory disorders, whether or not this is combined with an aphasoid problem

On the other hand, there is a clear relation between awareness and intelligibility that can be studied, for example, in the problems of geriatric audiology On much less secure bases, one can observe awareness of sound in a child (assuming that there is good evidence of responses within normal range), at much lower levels of intensity than can be used in terms of intelligibility Many older children who have had the advantage of good training in language are aware of sound at much lower levels than they can put to use It may be that a *listening* circuit is involved here

One more point, a matter that we have found confusing In the course of otologic and audiologic history we have all learned to use decibel notation in describing the intensity-loudness factors of an affected end-organ One wonders, however, how anybody can make a statement in terms of decibel notation when the problem lies high in the central mechanism The essence of this kind of problem is that it is not a pattern, it is not a constant, it does not remain "the same", therefore, the idea of describing a child with a central disorder, on the basis of subjective auditory responses, as having a 90-decibel hearing loss, is to my way of thinking absurd This is like taking blood pressure with a clinical thermometer, one might get some sort of a reading, but it would scarcely be descriptive of a dynamic state of affairs

DR IRA J HIRSH On this second question, concerning the use of tests for identifying a pathology, Madam Trenque writes—The first question to be answered is, is the lesion situated in the middle ear or in the internal ear? In her first paragraph she points out the well-known observation that when hearing loss exceeds approximately 60 decibels, one can assume that the inner ear is involved Now, if the deafness is less than 60 decibels, she has suggested that one make a bone conduction examination using conditioning techniques She suggests also that if the child is not well enough developed to accomplish the test procedure, one can use vocal tests to attempt to resolve the problem The child who has a transmission deafness, or conductive deafness, will repeat correctly familiar words that he knows, if one raises the intensity sufficiently above the threshold A child with trouble in the internal ear, even if one raises the intensity far above the threshold, will distort certain words, and the intelligibility will be below 100 per cent

The manner in which the child has developed language and speech is equally a good indication If the deafness is severe he will speak very little if at all, and the words that he uses will be simple and childish If the deafness is less severe, the child will not acquire complicated words The syntax will be defective and certain consonants will be deformed The child with a conductive deafness, with onset before the age of acquisition of speech, has a poor vocabulary but good articulation He presents only a more or less severe language retardation, and in effect he is troubled by a kind of all-or-none phenomenon either the sound is too weak and he doesn't hear it, or it is strong enough and he perceives it without distortion

As far as indication on the precise etiology of deafness is concerned, in cases of middle ear deafness, these factors are given by other clinical observations than the auditory tests, for example, malformations of the ear, otitis and toxicosis In case of deafness of the internal ear most of the time the etiology is difficult to establish in a definite manner, difficult to establish with certainty The nature of the auditory residuals and the form of the audiometric curve do not actually permit us to identify the etiology It is possible that the examination of a large group of children where the diagnostic etiology is certain will produce these interesting results in the future

From her own observations, she notes the following that meningitis is followed by rather severe destruction, with almost no hearing residuals or perhaps only islands in the low frequencies Rubella, on the other hand, gives curves situated between 60 and 80 db on the audiogram, and more or less horizontal Hereditary deafness appears to present a polymorphism in audiometric curves Nothing is identified with anything, I presume, in hereditary deafness Within the same family one finds a subject with a falling curve, another with a horizontal curve, in a third, complete deafness

The behavior of the child during the auditory tests very often permits the observation of phenomena superimposed, which point toward a central location for the deafness Such troubles can be motor, mental, psychological The test with a peep show and with pictures, from her point of view, are particularly interesting She gives, third, indications about the development of the deafness Auditory tests can permit us to follow the evolution of the deafness We have thus observed, for example, a functional recuperation of the order of ten or twenty decibels in children submitted to auditory training That is to say, the curve was raised, the threshold was lowered, during the first ten months of training, then it stabilized She has observed also a remarkable stability in the audiometric curves Deaf children whom they have followed are in a large majority those who were believed at first, from otological practice, to have hearing which does not continue to deteriorate

In conclusion, on this second question, the results of hearing tests, oriented toward auditory pathology, are limited, and it is absolutely necessary to supplement these tests in all young children by examining their mental capacity, their language and motor development, and their psychological factors thermometer, one might get some sort of a reading, but it would scarcely be descriptive of a dynamic state of affairs

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The child with a peripheral defect will usually startle fairly consistently to sounds above his threshold The child with a C N S defect may react at first to very weak stimuli, but soon becomes refractory to very intense sounds, or he may not react at all, even to the most intense sounds

If thresholds of auditory sensitivity can be reliably determined, children with peripheral lesions most often will show sloping audiograms with the high frequencies most severely affected Children with abnormalities of the C N S or central nervous system, may have normal thresholds, or frequently, hearing losses of about 60 db for all frequencies

Within any one test the child with a simple peripheral defect will usually show consistency of responses within the limits imposed by his age The child with an abnormality of the C N S will usually not be consistent in his responses, that is, his apparent threshold may fluctuate unpredictably by as much as 30 to 40 db Often it is impossible even to estimate the threshold for this child

A child with a simple peripheral defect is more readily conditioned than a child with a C N S defect to respond voluntarily to auditory signals This difficulty may be carried over into the conditioning of electrodermal responses to sound

In audiometry employing the electroencephalograph, the child with a C N S abnormality may sometimes show normal auditory sensitivity through electroencephalic responses while asleep, even though while awake he does not respond consistently to very intense sounds in other tests The child with a peripheral defect will show the same thresholds through electroencephalic responses when he is asleep as he does through overt responses when he is awake

When there are both peripheral and central abnormalities

DR ROBERT GOLDSTEIN Studies of pathologic anatomy provide us with only limited evidence that results on various hearing tests can be associated with various pathologic conditions This is mostly because studies relating hearing losses to histopathology have been restricted largely to peripheral auditory structures, and then mostly in adults In the studies of pathologic conditions in the central nervous system the accompanying audiologic studies have, in general, been inadequate We can say, however, that loss of auditory sensitivity is associated with organic defects of the auditory nerve and cochlea, problems of language comprehension and production with organic defects of some portion of the central nervous system We have very little knowledge of how much or what kind of central nervous system lesion may be responsible for loss of auditory sensitivity, or of how much damage there is in the periphery in persons with language dysfunction

We have available considerable information about some children, which allows us to compare results of hearing tests with educational progress, with development of skills of communication, and with general behavior In some of these children the pathologic basis of their auditory disorders are quite certain from other neurologic or physical defects, and from medical and developmental histories In the absence of any clearly defined pathologic condition, we can still infer the pathology on the basis of similarities in results on hearing tests and in educational development to children in whom the pathologic bases of their disorders are more certain, and yet, with all this information we cannot say with certainty that the results of hearing tests, or of educational progress, tell us more than *1* there is a reduction in sensitivity to sound, probably from a defect of the peripheral auditory mechanism, *2* there is a disturbance of auditory perception or of linguistic development probably because of some organic abnormality of the central nervous system, or C N S

When we examine very young children we do not have the opportunity to use hindsight from educational development to aid us in determining the nature of their auditory disorders We may have other than hearing tests to help us with our assessment, but let us assume that we must make a judgment on the basis of hearing tests only What kind of information can we get from them to help us decide whether the organic abnormality is in the periphery, in the C N S , or in both? In the limited time available, let us restrict ourselves to generalities, acknowledging in advance that there are exceptions to all of the generalities

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When there are both peripheral and central abnormalities in the same child the consistency or inconsistency with which a child responds may be the most significant differentiating criterion In such instances, however, we must derive additional differentiating information from other tests and observations

DR SILVERMAN We will refer now to the third question, and that is, what particular testing techniques have you found to be most successful in yielding answers to either or both of the first two questions?

DR WILLIAM G HARDY As to the third question, a good part of this has already been discussed Dr Goldstein just added more by implication I should like to make a few more observations

I believe we have all learned over the course of years that a fundamental technique is to get the clearest kind of evidence we can from parents who are thoughtful, careful observers Oftentimes we find that when we work with parents who have been thoughtful and clear in their observations, much of the clinical fancy-work that we do is simply corroborative

In the course of time we have come to value extremely highly the parents' answer to a simple question that has to do with the child's development, it produces particularly good dividends when there are other small children in the family "When this baby was three or four months old—not more than that—did you have any question about his hearing?" Oftentimes, when the ultimate picture indicates an aphasoid disorder, they answer "No" Oftentimes, when there is a severe central aberration of one sort or another, the answer is clearly "Yes" Oftentimes, the parents had not observed anything untoward, but this negative fact, itself, is important What we want to know, of course, is what can appropriately be called an auditory orienting reflex which should be present in infants who both receive and perceive sound

We like to see what children do in a controlled sound field, under highly structural circumstances, and watched by at least two trained observers Many kinds and levels of noise and sound are employed, the general type and range of which is clearly known Now, a three-month-old child does not wave his arms around and point to the sound-source, but one can see all sorts of reflexes and reactions, often localization, sometimes an interruption of his activities This last is a kind of negative response which, I believe, is entirely valid when judged as a reaction Usually, when we see these responses, and help the parents to recognize them, we return to some of the details of parental observation and jog their memories a bit Thereafter, they come through with many more comments of their own about things they have seen the child do, but have not believed their own eyes, because somebody had told them that their child was deaf This, to most parents, means a total thing (rare, indeed), so they stop expecting the child to respond to sound

I feel that I must take sharp issue with Dr Trenque, *in absentia*, on the etiology and the presumed fact of total deafness, because, from her description I do not know what she means by deafness We see hundreds and hundreds of post-meningitic children over the years, and I do not remember one that was totally deaf in the sense of complete loss of auditory reflexes For the most part, I believe, this business of the total, bilateral destruction of the peripheral mechanism is a thing that belongs in history Medicine in the past 20 years has changed all this considerably We are all well aware of the total involvement of unilateral impairments from various causes, but bilateral destruction is something different Of course, in an isolated instance, meningitis can still result in this but, fortunately, in communities with good medical care a child does not go two weeks without hospitalization and diagnosis If he did, one suspects, he would probably emerge totally deaf now, as he used to

I shall not say anything more about galvanic audiometry Our views on that are well known in the literature We are beginning to work seriously on E.E G audiometry, which has great possibilities, not only in measurement of function but also in furthering information about specific sites and modes of neuro-physiologic dysfunction Let me return to a comment made before. If one is dealing with a child who has some language and speech, the real point is a thorough test of speech-hearing This, too, needs to be believed A child who gives a subjective pure-tone audiogram of approximately 80 db in the speech-hearing range, but who then demonstrates a speech-hearing threshold as good as 40 decibels, is not an educatively deaf child Another small note of warning we see many children in the course of a largely consultative service who apparently have central auditory disorders, but who have been forced to use the heaviest duty hearing aids with maximum gains They have not wanted these aids, for the obvious reason that they have been given too much sound This warning will bear reiteration, for it is something about which great care must be taken in the field At stake here, in part, is a wide-eyed acceptance of a concept of deafness as a total kind of behavior, as though one were talking about a specific entity, always related to the same tissue, the same tissue-damage, and the same dysfunction It is extremely important in dealing with young children to determine whether the problem is peripheral or central, or combined—whether it involves both hearing and listening, or something else entirely, we also find—and believe that this is sensible practice—that oftentimes when one is quite sure that the peripheral mechanism functions fairly well and that there is evidence of a central involvement, a very mild-gain hearing aid may be salutary, largely as an attention-centering device This is a matter of judgment and experience, not only in terms of a test-picture but also all the rest of the picture which, to us, involves a most thorough otologic, pediatric, neurologic and often psychiatric appraisal

We were asked to discuss hearing tests One idea that has emerged from this discussion is that everybody who has spoken on these topics has agreed that hearing tests alone are not sufficient to describe these problems, more than that, that any one hearing test is totally inadequate to describe even a major part of the functions that relate to what I have been calling "reflexive hearing"

Just two more points I should like to commend attention to Dr Derbyshire's use of the term *aphasoid* This is a good term, because it does not have a direct relationship with the classical neurologic history of the *aphasia* that many of us have lived with More than that, it stresses the idea that we are not dealing with a little category of specific damage that can fit into a cubby-hole, the "oid" simply means *like* When a child is described as aphasoid in behavior, the describer is on safe ground, because he is presumably saying that the main trouble is not auditory, and that he wishes he knew better how to describe what is wrong with him

This world of ours needs to wake up to the needs of children who have these diverse, diffuse central language disorders, with or without central or peripheral auditory disorders Some of you gentlemen here at the Central Institute for the Deaf may forget that you are sitting in the "angel's chair" You have a curriculum and a faculty capable of moving a child back and forth, at need, from one stream of training to another To my knowledge, there are precious few other places in existence where this second problem, this aphasoid behavior, is even recognized, let alone where somebody is trying to do something about it

DR. IRA J HIRSH The usefulness of the test depends more on the method employed than on the particular test technique Auditory tests alone are incapable of resolving the problem as the risks of error are too great Auditory tests must be included in an ensemble of tests We ourselves proceed in the following manner in the first place, we make a very complete interrogation of the parents on the history of the child's genetic development, his motor behavior, his emotional, sensory, and intellectual behavior, the development of his language, and his family In the second place, we study the mental age of the child There exists in France a battery of non-verbal tests, established by Madame Borel-Maisonny, that we consider sufficient for a primary discrimination What we wish to know here is whether or not the child has a substantial mental retardation, and whether he is capable of accomplishing the audiometric tests In the third place, we study his language This language evaluation has two objectives first, to analyze difficulties in the language behavior itself The alterations in language can be subsumed under two groups of phenomena First, the tonal quality of the voice, the rhythm and articulation, when these are very altered the child's language is only a babble, (French, charabia), only once in a while modulated by a recognizable word The second concerns the understanding of words and their memorization, changes in syntax and automatic responses and verbalizations The first category is the fact of peripheral deafness, and the second indicates disorders of central origin

Fourth, we proceed to the auditory tests We always use tests with noise, or pure tones, and the spoken voice The principal basis for the voice tests, to which we attach great importance, is the utilization of responses that the child already has, and these can be established in collaboration with his parents Can the child respond to his name, some words that he seems to understand, what are some of his vocalizations, the words that he can pronounce and others that he can understand? The tonal test that we find most useful is the peep show, because it can be used relatively early, in certain intelligent children at the age of three years, in others at four years of mental age This age is precisely the one at which we wish to begin intensive training The second reason for using the peep show is that it is very precise Our experience in this area is abundant We have been using it for seven years Third, the behavior of the child during the course of the test is rich in revelations of his own character and capacities for attention, self-control, comprehension and emotional behavior

Among the vocal tests our preference is for a test with pictures We have assembled a large collection of pictures, among which we always find objects or animals that are interesting to a child We name them with a term that he uses himself, or that he can learn If a child does not speak, but is capable of designating these objects with some name or other, even though incorrect, this name is used in the test The test permits us to learn very rapidly the capacities both for hearing and for lipreading in the child

Dr Robert Goldstein For every child we try to get as much information as possible from extensive case histories, from psychometric examinations, from neurologic examinations when possible, and from careful observations of general behavior For today, however, I shall limit myself to the usual kinds of hearing tests we use to learn the nature of auditory disorders, in order to make educational recommendations

In all of our hearing tests we look for at least two things one, the weakest sound to which a child will respond, that is, his threshold, two, the manner in which he responds to sound

First of all we look for overt reactions to sound, either startle responses or voluntary responses Ordinarily, it is difficult to obtain startle responses at a child's threshold, but if we begin with weak sounds first and gradually increase the intensity, we may get the first reaction close to threshold Almost any child will cease to react to the same kind of sound, even at high intensities, if that sound is repeated frequently Variation in the kind of stimuli does much to delay this adaptation to sound The child with a C N S abnormality tends to ignore sounds sooner than the child with a simple peripheral abnormality

Whenever it is possible, we attempt to condition a child to make a voluntary response, such as removing a peg from a board when he hears a sound The child with an abnormality of the C N S is much more difficult to condition than a child with a peripheral defect In any case, we extend ourselves as much as possible to condition a child in order to get him to respond at the limit of his sensitivity

When our findings on the basis of overt behavior are too vague to be dependable, we try to determine a child's auditory threshold indirectly by using electrophysiologic reactions to sound as indicators of "hearing" We attempt to condition electrodermal responses, better known to you as GSR, to sound with electric shock as the unconditioned stimulus Or we examine electroencephalic responses to sound, that is, changes in the brain waves in response to sound while the child is asleep We do not attempt to condition electroencephalic responses In both electrodermal and electroencephalic audiometry we try to be as objective as possible in our judgments of electrical responses, which we analyze, by the way, only after our test is finished, however, we do make note of any overt responses during our tests

As in the case of conditioning voluntary responses, it is generally more difficult to condition electrodermal responses to sound in children with C N S defects than in children with peripheral defects This is by no means a clear differentiating criterion because there are many deaf children and many normal children who are also difficult to condition

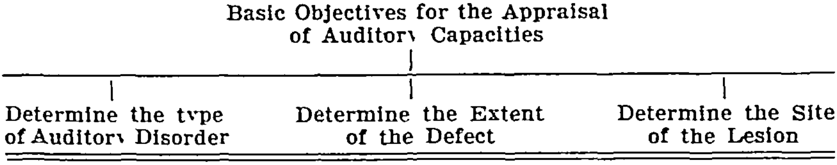
In our brief experience with electroencephalic audiometry we have found that it works as successfully with the children we call aphasic as it does with deaf children We see on a few occasions that children with C N S abnormalities give responses to significantly weaker sounds than ever consistently elicit voluntary or electrodermal responses Ordinarily, though, there is good agreement among all tests as to threshold of auditory sensitivity when there are reasonably consistent responses in each of the tests

Sometimes we are successful in determining auditory thresholds by these indirect techniques, and sometimes we are not Most often, however, we get enough information to confirm, at least partially, what we are able to observe in the overt responses

In general summary, we try to condition voluntary responses to sound whenever possible and rely on startle responses when we cannot condition a child We push to the limit of auditory sensitivity but we note responses to supra-threshold stimuli as well, as indication of a child's ordinary reaction to sounds We attempt indirect determination of thresholds through electro-physiologic responses to sound when we cannot obtain reasonably consistent overt responses The child with loss of auditory sensitivity because of a defect of the auditory nerve or cochlea, that is, the deaf child, usually conditions fairly easily within the limits of his age, is reasonably consistent in his responses, and usually shows a greater loss of sensitivity for high frequencies than for low frequencies The child with a defect in auditory perception and in linguistic development, because of some C N S abnormality, is more difficult to condition, is usually inconsistent in his responses, and most often shows no loss or only a moderate loss of sensitivity

DR. SILVERMAN Dr Myklebust will give his answers to the questions in a single presentation

DR. HELMER MYKLEBUST Emphasis on the ways in which hearing tests can be useful in making educational recommendations is highly desirable Often hearing tests have been analyzed in terms of their significance in psychophysiology without reference to the implications of the results for the child's education and general adjustment When we study the objectives for appraising a child's auditory capacities we find there are at least three basic goals (a) to determine the type or nature of the auditory incapacity, (b) to determine the extent or the degree of the defect, and (c) to ascertain the site or sites of the lesion This is shown schematically in Fig 1


Basic Objectives for the Appraisal of Auditory Capacities

Determine the type of Auditory Disorder

Determine the Extent of the Defect

Determine the Site of the Lesion

Fig 1.

The Primary Types of Auditory Disorders

| | |
|---|---|
| Peripheral Deafness | (End Organ) |
| Central Deafness | (Auditory Pathways) |
| Psychic Deafness | (Mental Illness) |
| Perceptual Disorder | (Listening Defect) |
| Receptive Aphasia | (Language Disorder) |
| Auditory Agnosia | (No Sound Meaning) |
| Overlapping Conditions | (Multiple Disorders) |

Fig 2

There are six conditions encountered in the appraisal of auditory disorders in young children, as shown in Fig 2 The seventh possibility is that more than one deficiency is present, necessitating the determination of overlapping conditions

Peripheral deafness refers to end-organ defect Central deafness means that the auditory pathways in the central nervous system have been impaired and that the nerve impulses do not reach the interpretation area in the auditory cortex This impairment falls essentially between the cochlear nuclei and the medial geniculate bodies

Psychic deafness is the condition whereby the child has adequate capacities organically but rejects sound for reasons of emotional disintegration It is our experience that psychic deafness in young children occurs mainly in psychotic children, but might be present in the severely neurotic

Receptive aphasia occurs as a result of damage to the interpretation area in the temporal lobe It is a symbolic language disorder and is present with considerable frequency in young children

Auditory agnosia refers to the condition resulting from gross damage to the auditory cortex Apparently this condition occurs only rarely When it is present the child cannot attach meaning to any sound although he has normal hearing acuity

Auditory perceptual disorders are complex and may affect the normal auditory process in various ways Figure-ground may be disturbed with the result that the child cannot use the auditory field selectively, thus, he can hear, but he cannot listen Auditory memory and discrimination also may be involved

Overlapping conditions refer to the presence of more than one defect Perhaps one of the primary problems relative to hearing impaired children is the multiple handicap of hearing loss and brain damage

Complete auditory appraisal assumes that each of these conditions has been considered and that the specific type of auditory disorder has been determined

Now we come to the second major objective, the determination of the extent or the degree of the defect If peripheral deafness is present it is essential to ascertain the degree of the hearing loss For educational purposes the most significant single factor in this connection is the extent to which the deafness has affected language acquisition and usage Four major classifications of degree of deafness relative to educational recommendations are shown in Fig 3

Children with a moderate hearing loss do not require specialized educational procedures Their language abilities fall within normal limits Those who are severely hard of hearing require special educational methods, but they benefit substantially from the use of amplification The profoundly deaf child seems to gain very little educationally from amplification, and thereby is dependent upon the specialized techniques developed specifically by educators of the deaf The deafened child is one who has sustained profound deafness after five years of age and thus retains his language abilities, when profound deafness is sustained prior to five years of age usually the language which had been acquired is not retained

| The Degree of Deafness |
|---|
| Hard of Hearing (Moderate) |
| Heard of Hearing (Severe) |
| Profound Deafness |
| Deafened |

Fig 3

The Site of the Lesion in Auditory Disorders

| | |
|---|---|
| External Ear | (Atresias) |
| Middle Ear | (Conductive) |
| Inner Ear | (Nerve-cochlear) |
| Auditory Pathways | (C N S ) |
| Auditory Cortex | (Temporal Lobe) |

Fig 4

The third primary objective of the auditory appraisal is to determine the site of the lesion Five major sites of lesions to be considered in appraising auditory capacities are shown in Fig 4

Lesions of the external, middle, and inner ear traditionally are determined by tests of acuity, using the bone and air conduction methods. The most common type of deafness in young children is that which results from deficiency in the inner ear. Frequently, inner ear lesions can be predicted from the degree of the hearing loss, when losses of 60, 70, 80 db, or more are present it is apparent that the loss does not derive from a simple conductive involvement. Lesions of the central auditory pathways and of the auditory cortex are more difficult to determine objectively, however, some test suggestions are given later.

Age of Onset of the Auditory Disorder

| | |
|---|---|
| Prenatal Period | (Before Birth) |
| Pre-speech Age | (Birth to 2 yrs.) |
| Early Language Period | (2 to 5 yrs.) |
| Late Language Period | (After 5 yrs.) |

Fig. 5

Etiological Classification of Peripheral Deafness

| | |
|---|---|
| Endogenous—(All hereditary) | 22.6% |
| Exogenous—(All non hereditary) | |
| (a) Meningitis | 11.3% |
| (b) Other diseases | 27.8% |
| Undetermined (Unknown) | 38.3% |
| N = 822 | 100 % |

Fig. 6

Two other significant determinations from the point of view of educational recommendations are the age of onset and etiology. These do not derive directly from the auditory test itself, but they are factors that must be considered when interpreting the results. The importance of age of onset is indicated by the different nature of the educational recommendations when deafness is sustained in the pre-speech age, or after five years of age. The importance of etiology is indicated by the higher incidence of multiple handicaps, such as deafness and brain injury, when the deafness results from rubella, meningitis, or certain other diseases. The primary classifications of age of onset in young children are shown in Fig. 5.

The primary etiological classifications are shown in Fig. 6.

That etiological factors are significant in terms of educational recommendations is apparent from the fact that research reveals significant differences between the exogenous and endogenous in such areas as intelligence, motor capacities, and educational achievement

No one test of auditory capacity can satisfy all of our demands or goals Actually three essentially different types of tests are required This is illustrated in Fig 7

Diagnostic Appraisal of Auditory Capacities

| Peripheral Nervous System—End-Organ | Central Nervous System C N S Pathways and Auditory Cortex | Psychological Integrity Mental and Emotional Processes |
|---|---|---|
| Auditory Acuity ↔ | Integration and Use ↔ | Psychic Auditory Behavior |
| ) Conditioned play audiometry | (a) Listening Tests | (a) Scanning Tests |
| ) Sound field speech, gross sounds and pure tones | (b) Localization Tests | (b) Foreground background |
| ) PGSR | (c) Perceptual Tests | (c) Vocal monitoring |
| ) EEG | (d) Language Tests | (d) Imitation and Echolalia |
| ) Behavioral Symptoms | (e) Pain Sensitivity Tests | (e) Comprehensive-Selective |
| | (f) Behavioral Symptoms | (f) Behavioral Symptoms |

Fig 7

Most tests provide relevant information concerning the integrity of all three of these avenues For example, if a child is difficult to condition, either with PGSR or in conditioned play audiometry, there is a presumption that even though he might have a hearing loss, he is also brain damaged, mentally ill, or mentally deficient, however, some tests are more useful than others for ascertaining a specific type of integrity We have found listening tests to be highly useful in the study of children presenting problems of the brain damage type In general, receptive aphasic children have auditory perceptual disorders, and thus cannot give the sustained attention required in listening We are in the process of standardizing a battery of auditory perceptual tests on normal children and those with auditory disorders, and these tests show promise for use in diagnosis The implications of this study are shown in Fig 8

Normally we select sounds from the auditory field according to organismic exigencies at any particular moment This is illustrated by the arrows showing normal shifting of figure-ground We see also that a basic function of background hearing is scanning of the environment in order that the organismic homeostatic relationships can be maintained In contrast, foreground hearing serves the basic purposes requiring listening, especially for the purpose of communication

Auditory Perceptual Functioning and Figure-Ground Behavior

| Background Hearing | Normal shifting of<br>←——→<br>Figure ground | Foreground Hearing |
|---|---|---|
| Mandatory scanning of environment<br>Signaling warning<br>Homeostatic awareness | | Listening<br>Receptive language<br>Immediate needs of the organism |

Fig 8

In general, study of young children having auditory disorders suggests that they fall into groups on the basis of their auditory perceptual behavior Those having impaired hearing lose the background function of hearing and, therefore, are restricted to foreground hearing In psychic deafness the child relinquishes inter-personal relations by rejecting foreground hearing, but he retains the more peripheral or primitive background use of hearing The brain damaged child cannot structure the auditory world, so he is a victim of the entire sound field He cannot select an appropriate sound and attend to it to the extent that the organismic needs are achieved satisfactorily In a recent publication Dr Neff reported similar behavior in cats after ablation of parts of the auditory cortex

The child with central deafness seems deficient on tests of localization, this is in contrast to those with peripheral deafness, furthermore, these children seem to be reduced in pain level responsiveness They might have normal acuity by PGSR but do not have ability to monitor their vocalizations

A number of other characteristic responses might be given

Psychic deafness in young children frequently can be determined most satisfactorily by informal tests, or by a combination of formal and informal techniques Because these children tend to reject foreground hearing the test which is limited to background responses is most suitable Conditioning techniques frequently are unreliable with this group Tests requiring scanning of background, monitoring of vocalization, and selective comprehension have been helpful in ascertaining whether such children have normal hearing and are rejecting sound for emotional reasons

In young children presenting complex auditory disorders the hearing test alone frequently does not make it possible to make a differential diagnosis Often psychological, psychiatric, and neurological study must be included The total maturational aspects and the behavioral symptomatologies are critical factors

Of a group of 325 pre-school age children with auditory disorders there were eighty with peripheral deafness, sixty-eight with deafness with central involvement, one hundred and forty-two having aphasic and other types of central involvement, twenty-four with psychic deafness, and eleven mentally deficient A revealing aspect of this study was the high incidence of children having both deafness and brain injury and the slightly higher incidence of children having auditory disorders other than peripheral deafness This seems to us to highlight the importance of differential diagnosis and the implications for educational recommendations

DR SILVERMAN What we shall do first is to ask the panel to react with each other

DR HARDY Considering the independence of this group, I think there is a tremendous unanimity involved I do not know where Dr Hirsh stands I am becoming increasingly concerned about the use of the term "brain-injured" as a genetic reference to so many of these problems We see many more children who get that way from pre-natal events of one sort or another wherein there is no exterior evidence of injuries Neurologists examine these children and keep telling us that they can see no other evidence of brain injury, and our psychologists keep saying they can see no other particular evidence determinable except auditory perception

You have to be very careful about this concept so that it does not become a label attached to many of these children, because, in all truth, ninety-nine per cent of our school people will not accept a "brain-injured" child, whereas a deaf one is all right I would like to know what the panel thinks about that

DR MYKLEBUST Well, I might say that I quite agree that we need a better term, also, that, as we use the term, we do mean central involvement, not necessarily literally an involvement of the damage type It is entirely possible that some of these are biochemical, of course

I would like to comment on the latter part of Dr Hardy's comment just to this extent, that I suppose, central involvement, or damage, whichever kind of term we are going to use, is in the state today where there is no one key to it Sometimes the EDG shows it, sometimes a neurological shows it, sometimes the psychological shows it, etc Certainly, motor tests and other tests of this type are frequently useful in bringing this into the foreground It is essential that we use a multiphasic approach of study to this condition at this time

DR GOLDSTEIN I would like to make two comments about the use of the word or term "brain-injury", one is that I am in partial agreement with Dr Hardy that a person can have organic injury to the brain and have no obvious problems in communication He may have perfectly normal hearing, speech and language A person who does have problems in communication that cannot be attributed to a loss of sensitivity, to mental deficiency, or to psychic disturbance, may very well have a language disturbance of some sort presumably due to some abnormality of the organic central nervous system, in fact, we have enough indications to accept the aphazoid or aphasic behavior as a symptom of some central nervous system abnormality

I have a greater objection to the word "brain-injury" in parallel with the term "deafness" I think we should say either "ear-injury," "brain-injury" or "deafness" and some other language disturbances

**DR HIRSH** Dr Trenque has written a summary page which she entitles "Reflections on the Problem of Auditory Testing of the Young Child, and the Data that such Tests Supply"

At this stage of our experience, we consider that there are two categories of children relatively easy ones and difficult ones The relatively easy ones are the following First, purely deaf children, that is, children who are only deaf without other deficiencies superimposed One knows now the behavior of purely deaf children, their characteristic difficulties, and the retardation that follows the deafness in intellectual performance The diagnosis is fairly easy, and the measure of the amount of deafness can be established with precision after the age of four years The second category of relatively easy cases are mental defectives These are equally easy to screen It is more difficult to say whether a partial deafness is supplemented by mental retardation

The difficult cases are composed of the following groups children who have important psychic difficulties, aphasic children, deaf children with an intellectual or psychic deficit In our opinion, only a prolonged observation will permit the establishment of a diagnosis or prognosis that is precise Compensation for deafness depends essentially upon mental capacities and the social adaptation of the child One can only hope, even after a complete test of hearing, intellect and psychology of the child The real capacities for overcoming deafness cannot be appreciated definitively even in the course of the first stage of education, that is, at the acquisition of concrete vocabulary, reading and writing, but only after the child has acquired more complex notions of time, cause, attributes, etc

**DR MYKLEBUST** I think there is perhaps more agreement on this question than we had anticipated I suppose I could raise the question now as to whether we can classify children telling us that they can see no other evidence of brain injury, and our psychologists keep saying they can see no other particular evidence determinable except auditory perception

You have to be very careful about this concept so that it does not become a label attached to many of these children, because, in all truth, ninety-nine per cent of our school people will not accept a "brain-injured" child, whereas a deaf one is all right I would like to know what the panel thinks about that

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We should give our audience an opportunity to direct questions to any member of the panel

DR HIRSH I apologize for not being able to defend some of Dr Trenque's points here There were certain paragraphs in which I panicked before I got to the end, and this will be published in full when we publish the proceedings I thank Dr Bocca, who brought Dr Trenque's paper here He has seen her recently, and perhaps, from the discussion that comes from the floor he may wish to make a comment or two as to his reflections of her point of view on these matters

DR BOCCA I have no comment

DR SILVERMAN We shall now give our audience an opportunity to direct questions to any member of the panel

DR BRUCE M SIEGENTHALER I would like to direct a question to Dr Myklebust In your last slide you showed the results of the classification of three hundred and some children Will you comment as to what general population that has been drawn from? What are the factors that led to picking out these particular three hundred and twenty-five children?

DR. MYKLEBUST That is a very good point I am glad it comes up because I meant to mention, that this is a selected sample This is a sample of children who come to a hearing diagnostic center in a medical school They are definitely selective factors They have come there because they have very real problems

DR. SILVERMAN May I ask a question do you think that because we become interested in a certain kind of child, we may be looking at a very obscure sample in the way we operate?

DR MYKLEBUST I would agree with that entirely, and we must be careful about selected samples That is why, in another survey which does include children throughout the nation, we have stratified samples from all types of schools and age levels and so on I think it is a very important question I think it is very important to mention that the data there necessarily represent the basic things having certain kinds of language disorders as aphasic I find it difficult to see why we should not do so if the condition is comparable to that traditionally referred to with adults I do not see why we should confuse age of onset with classification The fact that the child sustains this prenatally or at the time of birth does not alter the basic classification

In deafness we specify early deafness by congenital deafness, in psychiatry, they use the term schizophrenia Childhood aphasia I wonder what you think about that

Dr Goldstein I would like to speak in support of that comment I think that simply because the term "aphasia" grew up around adults does not make it the particular property of adults People have objected to the use of "aphasia" in children because of the obvious differences in behavior of the adult aphasic They say that the person who has sustained an accident is so different from the child who never developed language, but, have you ever stopped to compare an adult who suddenly loses hearing to a child who never had any hearing There is a tremendous difference in many aspects between these two people, and yet, if they have certain symptoms in common, we have no objection to calling the adult "deaf" and the child "deaf"

Dr Hardy I object to calling either of them deaf Let us consider how much hearing they have

I would like to play along with this idea of childhood aphasia with a proviso or two first, the field of neurology is beginning to learn what we are talking about in terms of functional and developmental aspects of these problems I am not sure that is a general truth at present, second, everybody who addresses this concept of childhood aphasia really makes a serious effort to include and distinguish this business of auditory perception or imperception and stop talking about, let's say, a peripheral child with aphasia The only qualification is that these things be made inclusive and exclusive in one way, whether one is discussing auditory information as the lack of development, or damage to the centers which have to handle that information as the lack of development, and how these two get together perhaps not so true of the individual with the difference in the two ears

It seems to me that it is something worth watching and worth testing for increasingly I think we have a great deal to learn with this localization and its validity and reliability and so on We do feel that there is a correlation between it and damages that cannot be explained on the basis of peripheral involvement

DR HARDY Dr Trenque agrees with that observation I should think that where there is a profound involvement this would not be too critical a point, because, it is our experience that when it is profound, either peripheral or central, it is bilateral, both sides are involved Oftentimes there are conductive lesions, or acute otitis more severe in one side or the other

This business of undertaking audiologic appraisal of these young children without a full foreground and background of the best possible work is for the birds, as we may say You have all the information possible about the organic state of the child I think that would tend to direct the thinking

MR JACK ROSEN I am particularly pleased to have so much attention called to the central problems, but, at the same time, I would like to call attention to the fact that there is no law which requires that a child have only one problem, even if there were, children would not obey it

The purpose of this remark is that the central problems are determined upon the basis of symptoms which are not auditory for the most part It is quite possible, and in fact, very often it does occur that children do have hearing losses and some of these other symptoms at the same time There is a tendency, when attention is called to a new phenomenon, to disregard some of the older phenomena and techniques, and I would be particularly concerned about the neglect of careful audiological evaluation before deciding that a child has only a central problem or only a psychic deafness, because this can lead to serious problems I would also be very care-

DR R N REILLY During the discussion of the successful techniques none of the members of the panel have mentioned the question of frequency modulation in testing young children When I was in the Netherlands three years ago, Dr Huizing was using frequency modulation in testing babies and young children, and during the past six months I have used it with quite a good deal of success I wonder what the comment of the panel would be in relation to that?

DR HARDY I think, Dr Reilly, that this simply reflects the time We have used frequency modulation for six or seven years as part and parcel of the pure tone presentation in subjects It is a wonderful attention centering device and oftentimes, as you play back and forth between a steady pulse tone and then introduce modulation, you get responses you cannot get otherwise, particularly with C N S involved children, I think

DR MAURICE H MILLER Dr Myklebust mentioned that the child with a central disorder will have difficulty, or may have difficulty, in localizing sound Will not a child with a peripheral problem also have difficulty in localization if there is a large difference in the acuity between ears, and is this not a factor of the difference between ears rather than with the site of the lesion?

DR SILVERMAN May I repeat the question The question is first in the form of a comment that Dr Myklebust indicated that difficulty in localization might indicate a lesion of the central nervous system Dr Miller raises the question as to whether that might not be true of end-organ or middle ear deafness, for that matter, and may be related to a difference in sensitivity in the two ears

DR MYKLEBUST Yes, of course Difference of degree of involvement of the two ears might very well be affecting localization response As such, we can do nothing but accept it and entirely agree that it is a very real possibility

I suppose I am referring to something more like this, that in certain children, and this is not specifically those with, let's say, a simple peripheral involvement, not only do they not localize, but they do not attempt to localize This is perhaps not so true of the individual with the difference in the two ears

It seems to me that it is something worth watching and worth testing for increasingly I think we have a great deal to learn with this localization and its validity and reliability and so on We do feel that there is a correlation between it and damages that cannot be explained on the basis of peripheral involvement

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Dr Silverman I shall now attempt to summarize the panel deliberations

The panel directed its attention to three questions one having to do with the goals set, particularly with reference to educational recommendations and the testing of the hearing of young children, two, the evidence for the results of hearing tests that can yield information about the pathology or auditory and other disorders, and three, what particular techniques are used

The panel seemed to be concerned with the differentiation of end-organ from other types of lesions, and at one time seemed to work on the anatomy, another time on the dimensions of behavior, and still another time on the dimensions of ease of conditioning

They seem to go from one to the other, and they seem to admit that it was difficult to follow the outline In one case we got the words "conductive" and "language" in the same column, and in another case we get a little bit of anatomy and behavior in another column, but this, again, is a matter of groping for the universals to describe certain kinds of conditions that are observed

There seemed to be unanimity with what was stated so succinctly by Dr Trenque, that there are easy and difficult cases What we are trying to do, apparently, is to supplement what seems to be a good deal of clinical artistry All of this is involved We have to develop more objective techniques

One thing surprises me, however, about the statements of the panel here, or one omission—and I know they are aware of this—and that is the validation of some of the statements that have been made For example, from the audience there was a comment about a test's being good What are the dimensions of goodness in terms of the behavior of the child as he develops?

I also was surprised that there was as much agreement among the people. I looked forward to bringing them together, and I am delighted that we have had this opportunity to have all of them I express our gratitude

## II DIAGNOSIS OF HEARING DISORDERS

After a brief recess, the International Conference on Audiology reconvened in the Auditorium of the Washington University School of Medicine, St Louis, Missouri, Dr Ira J Hirsh, presiding

Dr Hirsh We will now continue this afternoon's symposium on the Assessment of Auditory Function We have discussed so far tests appropriate to young children, and now we propose to approach an area that represents probably the closest connection between the disciplines of otology and audiology

## AUDIOMETRY IN DIAGNOSIS

Raymond Carhart,

Evanston, Ill

### I

The subject of audiometry in diagnosis has no many ramifications that one cannot hope to discuss it fully in a single paper, moreover, the subject is one to which both research and clinical contributions are continuously being made, so that any review one undertakes today will seem inadequate tomorrow Realism requires that the present discussion be restricted appropriately

To this end, only the relationships between measurement of thresholds for pure tones and diagnosis of hearing disorders are here considered The importance of speech audiometry, the significance of supra-threshold function in response to pure tones and to noise, and the value of special techniques, such as psychogalvanic audiometry are obvious Each of these topics is worthy of extensive coverage, but the present discussion is arbitrarily restricted to a review of major principles in interpreting conventional threshold audiograms and to an examination, through examples, of the fact that the formulation of additional principles may be anticipated

## II

The air conduction audiogram conveys substantial information of diagnostic importance

For one thing, air conduction curves are sufficiently typical in some types of hearing loss so that the audiometric pattern suggests a possible etiology to the clinician The most obvious illustration of such a situation is the notched curve showing loss for high frequencies, which leads one to suspect noise-induced hearing loss Another example is the gradual deterioration in acuity for higher frequencies so characteristic of presbycusis In contrast, there is the relatively flat loss of about 50 db which is slightly more pronounced for low frequencies than for high frequencies Such a curve is likely to result from marked stapes fixation, from certain other conductive lesions, or from labyrinthine hydrops, if it is of the sensori-neural variety Again, a trough-shaped audiogram which tends to follow an equal-loudness curve, *i e*, an equal phon contour, immediately suggest the possibility of a non-organic hearing loss, thus, while threshold pattern alone never allows definitive diagnosis, the details of the air conduction curve often contribute to such diagnosis It is, therefore, pertinent to continue an interest in the types of curves which categorize varieties of hearing impairment, and to seek further insight into the inter-dependencies between the two

As a corollary to the foregoing observation, the relationship between the two air conduction curves obtained from a single patient tends also to distinguish varieties of hearing loss Bilaterally symmetrical impairments are relatively common in some conditions, such as in endogenous congenital losses, and in presbycusis Moderate dissymmetry of loss is usually observed in other conditions, for example, in hearing losses due to anoxia at birth, or to otosclerosis Other pathologies most commonly affect hearing in one ear primarily or exclusively One illustration is the complete unilateral destruction of auditory function which mumps sometimes cause Similarly, acoustic neurinomas, temporal bone fractures, and sudden vascular disturbances usually are unilateral and, hence, effect audiometric results in only one ear Again, cases with labyrinthine hydrops often show depressed hearing in only one ear, although this condition may manifest itself bilaterally, and hearing loss tends to fluctuate markedly In consequence of tendencies such as those just mentioned, the clinician can frequently utilize his observations on the audiometric balance between ears as a helpful segment of the information he requires in order to reach his diagnostic judgment

III

The fact that the relationship between air and bone conduction thresholds assists in distinguishing sensori-neural involvements from lesions in the external and middle ear is, in the minds of many people, one of the most important diagnostic applications of pure-tone audiometry The principles involved are generally accepted It is clearly recognized that adequate determination of bone conduction thresholds requires precautions of calibration and of test administration beyond those which are necessary for good air conduction audiometry When such precautions have been taken and the patient has an organic loss, the general level of the bone conduction curves indicates the degree of sensori-neural involvement (without distinguishing between cochlear and retrocochlear sites) If the air conduction curve lies at the same level, the total loss may be judged as sensori-neural By contrast, there cannot be a sensori-neural involvement when acuity by bone conduction is normal Here, any substantial depression of acuity for air-borne stimuli must be due to a lesion in the transmissional system In other words, such a relationship indicates a conductive loss The third alternative is the condition where both bone and air conduction curves are depressed, but where the loss by air is significantly greater than by bone In such an instance, the depression of the bone curve bespeaks a sensori-neural component of loss, while the further depression in acuity for air-borne sound is evidence of a concomitant conductive, or a transmissional, loss One is here faced with a composite loss or, as some would still term it, a mixed loss

## IV

In recent years it has become increasingly apparent that the clinical audiogram contains a host of subtler clues which can contribute to finer diagnostic differentiation A few of these are currently known, as is illustrated in the subsequent sections of this paper It is imperative to remember, however, that the clinical audiogram contains additional clues Some of these await discovery, while the significance of others needs clarification The generalization which must be stressed at the outset is that clinicians have tended to discount subtler configurational features of the audiograms at their disposal and, hence, have failed to gain full benefit from these test records True, much research is needed to catalogue all the aids to differential diagnosis which reside in good clinical audiograms For the moment, however, the important points are that known clues are not being used fully, and that clinicians, on the whole, are not actively curious about the less obvious significance of the pure-tone audiogram

## V

Particularly good illustrations of subtle audiometric clues are found in the bone conduction curves characterizing different kinds of transmissional deafness Mechanical lesions tend to cause distinctive distortions in bone conduction audiograms These distortions are slight, and they are due to changes in the physical constants of the auditory system rather than to modifications of sensori-neural activity In other words, the effective agitation reaching the organ of Corti from a bone conduction oscillator can be influenced to a measurable degree by the condition of the middle ear and of the external ear

Fixation of the stapes, for example, induces such mechanical modification in the bone conduction audiogram Fig 1 presents a record which is characteristic of this condition The patient involved was diagnosed as having clinical otosclerosis without secondary nerve degeneration For sake of simplicity, the responses for only one ear are shown in the figure The significant feature of this audiogram, for the moment, is that the depression of the bone curve which one notes at frequencies above 500 cycles, is an artifact in the sense that the normal state of the patient's inner ear is not revealed with full accuracy Failure to consider this artifact when interpreting the audiogram would lead to the erroneous conclusion that the patient possessed a mild sensori-neural involvement Conversely, awareness that this general pattern of mechanical distortion in the bone curve is typical of stapes fixation increases the diagnostic value of the audiometric record

As one would expect, the mechanically produced modification in bone conduction response consequent to stapes fixation varies from patient to patient At least in most cases, however, these variations are not so great that they obscure the general pattern of shift characterizing stapes fixation Most typically, the mechanical shift in the bone conduction curve induced by stapes fixation is of the magnitude and of the shape represented by the shaded area in Fig 1 That is, an otosclerotic patient with normal cochlear function, which would be revealed by a bone conduction audiogram at normal if it were not for the mechanical shift in responsiveness, will most typically yield a notch-like depression of the bone curve which follows the lower boundary of the shaded area in the figure The audiogram shown in Fig 1 did not conform perfectly to this course, but the deviation did not obscure the basic pattern characteristically induced by stapes fixation

Such a notched depression in the bone curve is less obvious to the eye when secondary nerve degeneration is combined with stapes fixation, but it is nonetheless present A typical audiometric record illustrating this situation is shown in Fig 2 The position of the bone conduction curve is shifted and given a downward tilt toward the right by the senori-neural loss which is present in this case If this sensori neural condition were the only impairment present, there would be a smooth progressive drop in acuity with increase in stimulus frequency, however, the smoothness of this pro-

gression is obscured by the mechanical distortion in the bone curve which stapes fixation caused Stated conversely, the trade-mark of stapes fixation is to be found in this record, if the clinician wishes to seek it The break which occurs in the bone conduction curve at 2000 c p s is the preliminary clue to mechanical distortion in the curve Confirmation is

AUDIOMETRIC RECORD

Name Miss. M.B. Date 1-19-49

Audiometer Test By J C Audiometer Used A

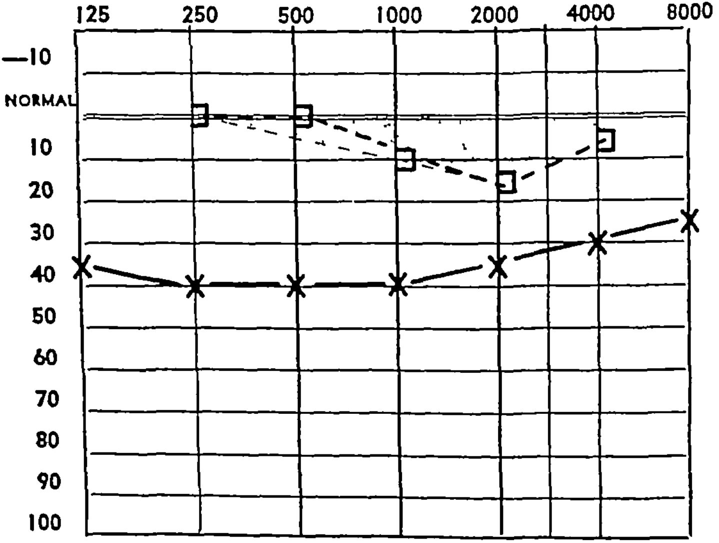

Fig 1 Hearing levels for the left ear of a 17-year-old girl having clinical otosclerosis without secondary nerve involvement Stippled area indicates usual magnitude of change in bone thresholds induced mechanically by stapes fixation

achieved by subtracting the idealized mechanical notch from the bone curve The residue thus obtained reveals graphically the so-called cochlear reserve, that is, the configuration of sensori-neural acuity which the patient has retained In the present instance, this residue is characterized by the smooth progression in loss for higher frequencies mentioned previously

## VI

Many other conductive lesions produce shifts in the bone conduction audiogram Here, physical similarity among lesions, regardless of etiological classification, will determine a particular audiometric configuration For example, permanent damages resulting from otitis media can not all show the

AUDIOMETRIC RECORD

Name Mrs. B. J. Date 11-22-49

Audiometer Test By F M Audiometer Used M

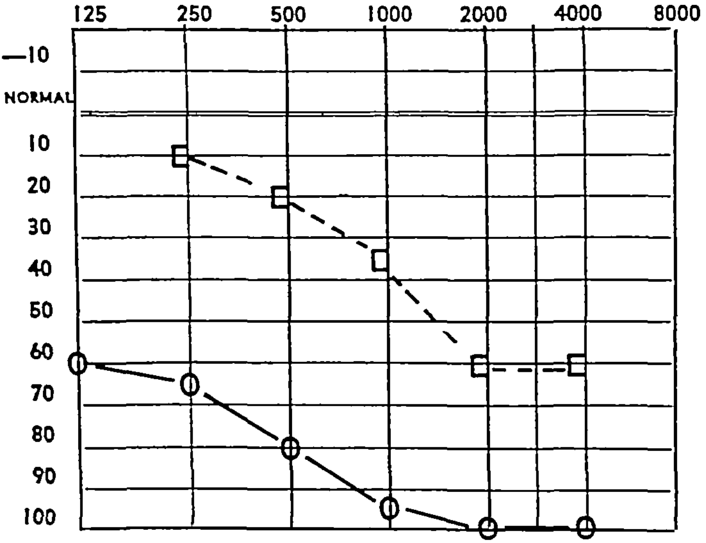

Fig 2 Hearing levels for the right ear of a 40-year-old woman having complete stapes fixation due to clinical otosclerosis plus secondary nerve degeneration

same pattern of mechanical artifact in the bone curve simply because they do not all produce equivalent damage in the middle ear mechanism, moreover, until clinicians learn to classify each conductive lesion on the basis of distinctions in the mechanical damage which characterize it, they will be limited in the precision with which they can differentiate among meaningful artifacts in the bone conduction curve

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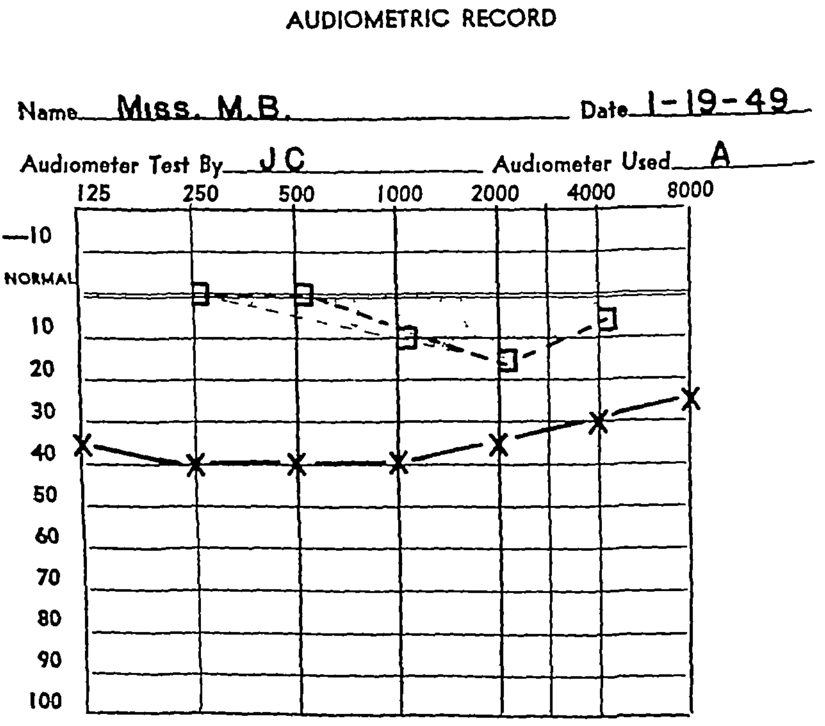

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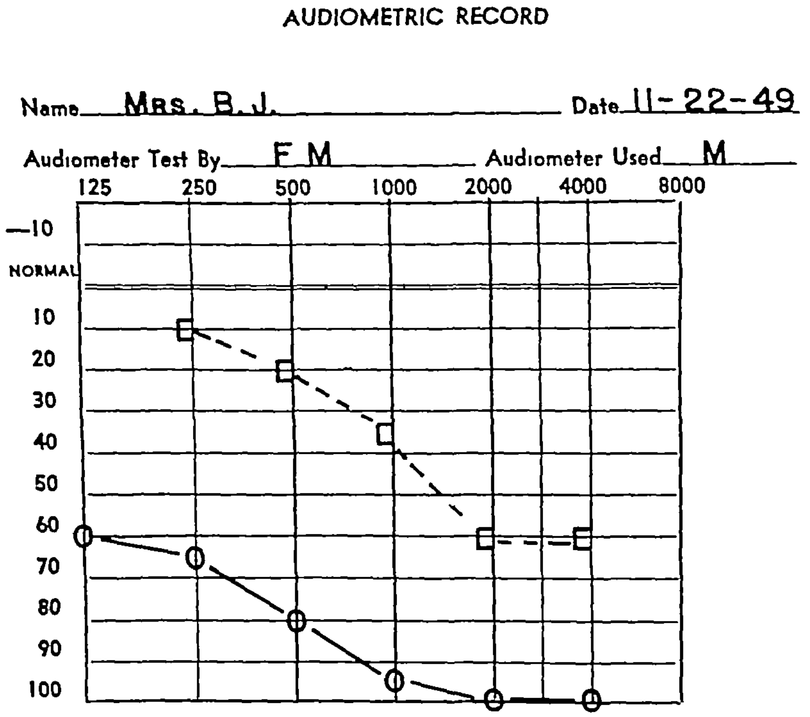

AUDIOMETRIC RECORD

Name Mrs. B.J. Date 11-22-49

Audiometer Test By F M Audiometer Used M

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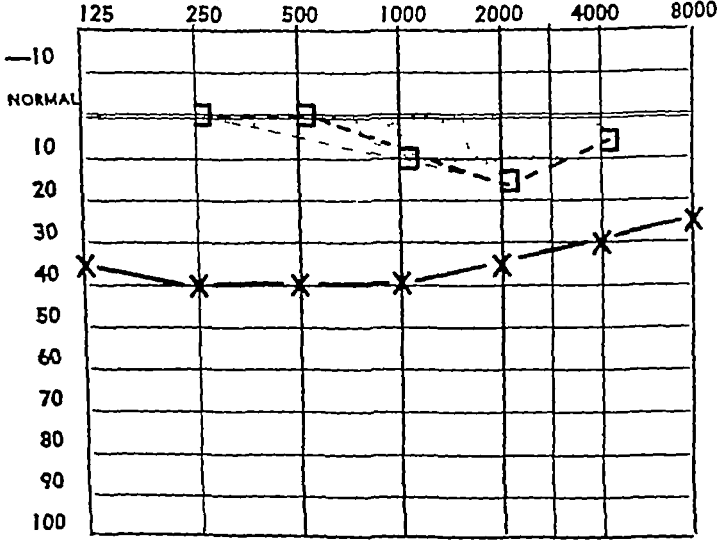


Fig 1 Hearing levels for the left ear of a 17-year-old girl having clinical otosclerosis without secondary nerve involvement Stippled area indicates usual magnitude of change in bone thresholds induced mechanically by stapes fixation

achieved by subtracting the idealized mechanical notch from the bone curve The residue thus obtained reveals graphically the so-called cochlear reserve, that is, the configuration of sensori-neural acuity which the patient has retained In the present instance, this residue is characterized by the smooth progression in loss for higher frequencies mentioned previously

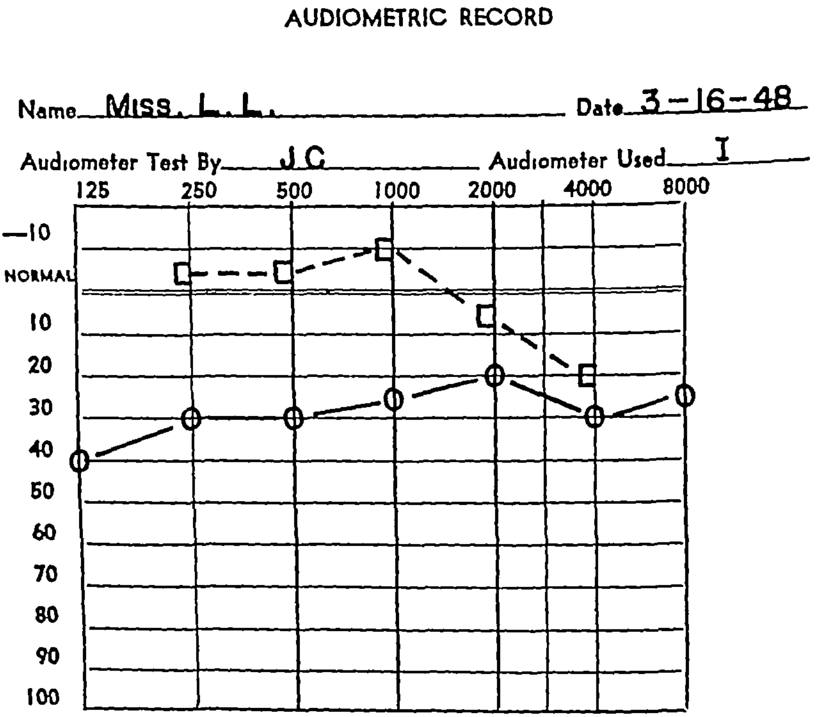
chanically Specifically, the case reported in Fig 3 probably did not possess either cochlear hyperacuity for low frequencies or sensori-neural deficiency for high frequencies One reason for arriving at this conclusion is the fact that the patient did not show a high frequency drop by air conduction comparable to the drop by bone This patient's air conduction audiogram, in other words, has a configuration which bespeaks a conductive lesion without appreciable sensori-neural involvement There is a second reason for expressing belief that the pattern of bone conduction response under consideration is mechanically induced Many cases showing this pattern reveal sudden modification in the pattern of the bone curve as soon as the mechanical status of the middle ear is changed One example which comes to mind is a case wherein the bone conduction curve reverted essentially to normal when the patient's perforated ear drum was closed with a paper patch

It is likely that clinicians have often mistakenly interpreted minor decreases in bone efficiency at higher frequencies as evidence of mild sensori-neural involvement Such a sensori-neural involvement is properly assignable only if the air conduction curve incorporates a break in its course that also indicates decrease in acuity for high frequencies When concomitant depression of the air conduction curve is not found, a minor depression in the bone conduction curve should be presumed to be evidence of mechanical modification in the conductive mechanism A similar interpretation is assignable to minor elevations in the bone curve

One must reiterate that it is not currently possible to state the specific nature of the mechanical changes underlying a particular pattern of shift in bone responsiveness Bone conduction audiometry will have increased diagnostic usefulness when research reveals the relationships which are involved The first step is to develop sufficient confidence in the existence of such relations so that they are sought out systematically and their meaning is mastered, moreover, the clinician must remember that, if the patient has lesion or pathology in the middle ear or the external ear, the exact picture of cochlear sensitivity is seldom revealed by the bone conduction

Certain patterns are nonetheless emerging It is possible to illustrate in general terms the value which the clinician can gain from further knowledge of the subtle clues that reside in a good bone conduction audiogram

As one example, consider Fig 3 Again, the results for only one ear are reported The diagnosis in this case was conductive hearing loss due to chronic suppurative otitis media The important thing is that the responses by bone conduction show a pattern frequently observed when there is disease in the middle ear This pattern, which was described years ago by Lierle and Reger,[15] is characterized at low frequencies by better than normal responsiveness to bone stimuli, and by reduced responsiveness at high frequencies In many instances the entire configuration is probably induced me-

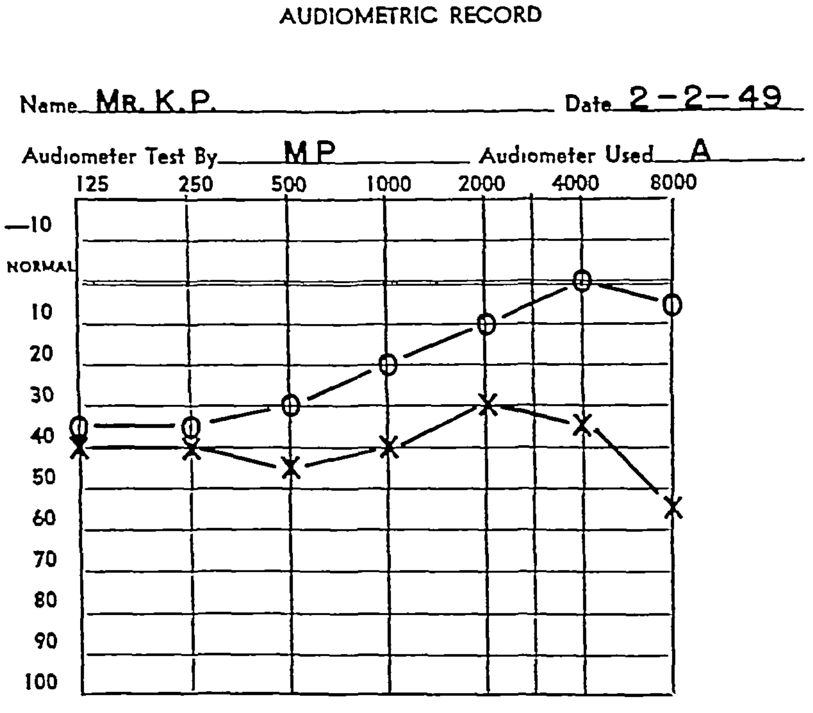

AUDIOMETRIC RECORD

Name Miss. L. L. Date 3-16-48

Audiometer Test By J.C. Audiometer Used I

Fig 3 Hearing levels for the right ear of a 13-year-old girl having chronic suppurative otitis media

dismissed The alternative, an increase in stiffness, is credible when one remembers that the encroaching spicules of otosclerotic bone impose a reduction in the freedom of stapedial movement In a technical sense, the elasticity of the ossicular system is sharply increased at the oval window by this encroachment, moreover, this effect will continue to be the main one as long as some stapedial motility remains The mechanical state must change radically when fixation becomes complete The stapedial footplate must now be so firmly locked within the oval window that the stapes is loaded, at least to some degree, by the mass of the skull This increased mass should reduce the capacity of the system to transmit high frequencies One notes, in Fig 4, that the added im-



AUDIOMETRIC RECORD

Name MR. K. P. Date 2-2-49

Audiometer Test By M P Audiometer Used A

Fig 4 Hearing levels for air conduction exhibited by a 51-year-old man having clinical otosclerosis without secondary nerve degeneration. The right ear with incomplete stapes fixation reveals loss at low frequencies suggestive of stiffness" increase The left ear with complete stapes fixation shows an additional loss at the high frequencies suggestive of mass increase

audiogram True, the general level of cochlear sensitivity may be estimated from this audiogram, but the details of apparent responsiveness will often be distorted by mechanical influences The clinician must make allowances for these influences when estimating the sensori-neural efficiency of a patient with a conductive involvement

## VII

Much attention has been given in recent years to the concept that anticipable shifts in air conduction acuity are induced by changes in the mechanical impedance of the auditory system The writings of Metz,[16] Johansen,[10] and Campbell[2] are sufficiently well known so that they need not be reviewed here

The important idea is that the clinician can find value in these concepts when he is interpreting conductive losses Here the configuration of thresholds for air-borne stimuli may be viewed as a manifestation of specific changes which have taken place in the physical constants of the ear Naturally, the clinician is not going to attempt detailed mathematical analyses of individual case records, however, he can profitably bear in mind the general principles which the physicist has made available to him, and which appear consistent with clinical experience, namely, that increased stiffness or decreased mass reduce sensitivity for low frequencies, whereas the reverse conditions reduce response to high frequencies

Consider, as one example, the case shown in Fig 4 Only the two air conduction audiograms are here reported This patient was diagnosed as having clinical otosclerosis without secondary nerve degeneration The stapes was found to be only partially fixed on the right side, but completely fixed on the left The hearing loss in the right ear is substantial for low frequencies and mild for high frequencies According to the principles mentioned above, such a configuration could be either the result of mass decrease or of stiffness increase Since a substantial decrease in the effective mass of the conductive system is inconsistent with the pathology of otosclerosis, the first of these possibilities may be quickly dismissed The alternative, an increase in stiffness, is credible when one remembers that the encroaching spicules of otosclerotic bone impose a reduction in the freedom of stapedial movement In a technical sense, the elasticity of the ossicular system is sharply increased at the oval window by this encroachment, moreover, this effect will continue to be the main one as long as some stapedial motility remains The mechanical state must change radically when fixation becomes complete The stapedial footplate must now be so firmly locked within the oval window that the stapes is loaded, at least to some degree, by the mass of the skull This increased mass should reduce the capacity of the system to transmit high frequencies One notes, in Fig 4, that the added im-

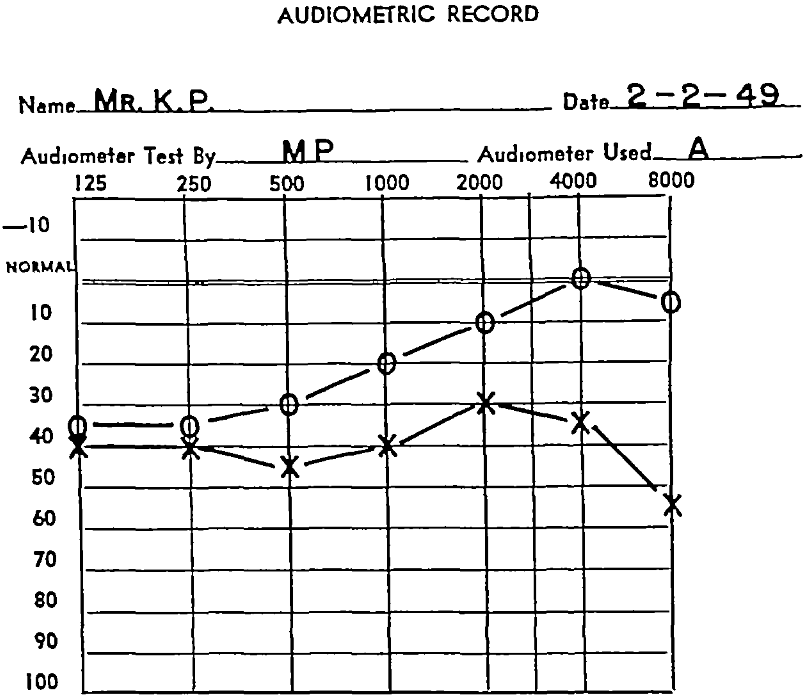


Fig 4 Hearing levels for air conduction exhibited by a 51-year-old man having clinical otosclerosis without secondary nerve degeneration The right ear with incomplete stapes fixation reveals loss at low frequencies suggestive of stiffness increase The left ear with complete stapes fixation shows an additional loss at the high frequencies suggestive of mass increase

pairment exhibited by the left ear, where the stapes was completely fixed, is of this very nature

The foregoing discussion is schematic, but it illustrates the manner in which awareness of physical concepts can enhance the clinician's evaluation of the hearing losses he observes A further illustration, with completely different practical

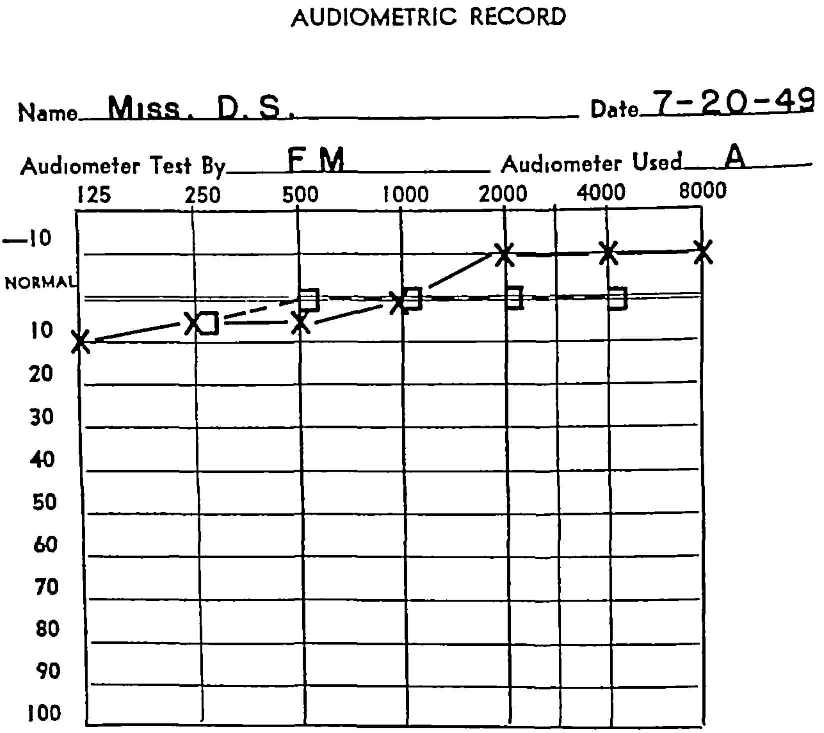


Fig 5 Hearing levels for the normal left ear of a 37-year-old woman having clinical otosclerosis in the right ear The tilt of the air conduction curve in relation to the horizontal curve for bone conduction illustrates earliest audiometric clue to the onset of stapes fixation

implications, is to be found in the audiometric configuration of pre-clinical otosclerosis This configuration was suggested by Campbell[2] Graham[7] found the configuration to be common among teenagers and young adults whose hearing was "normal" and who had close relatives exhibiting otosclerosis The configuration is illustrated in Fig 5 It is characterized by a tilting of the air conduction curve without concomitant shift in the bone conduction response The tilting is sufficient so that an air conduction loss of 10 to 15 db appears at 125 cycles Hearing is near normal at 1000 and 2000 c p s Hyperacuity appears at still higher frequencies This tilting, when interpreted from the standpoint of impedance concepts, leads one to suspect increased stiffness within the conductive system As already pointed out, the mechanical effect of incomplete stapes fixation is to increase the stiffness of the system

The present instance represents a condition where the fixation process is so minor that hearing loss of clinically noticeable magnitude has not yet resulted Nonetheless, the audiogram shows a disturbance in responsiveness to air-borne stimuli which is attributable to minor changes in the conductive mechanism, and which is easily identified by the fact that the bone conduction curve does not reveal any evidence of this disturbance *

The exciting feature of this configuration, from the medical point of view, is that it reveals the presence of otosclerosis early enough so that preventive measures can be applied once they are discovered Thus, the time may come when clinical otosclerosis, as we know it today, will seldom be allowed to develop, because the disease can be discovered very early and can be controlled through medical, dietetic, or other non-surgical means

In summary, as exemplified by the cases just discussed, lesions of the conductive system produce changes in hearing which are consistent with the principles governing mechanical systems The clinician can facilitate his tasks in diagnosis by remaining alert to the manifestations of these principles which appear in the air conduction audiogram [11]

## VIII

The problem of differentiating among sensori-neural losses is complicated One task is to segregate cochlear (end-organ) lesions from retro-cochlear (neural) lesions A further task

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*The mechanical effects are so minor at this stage that the notched depression of the bone curve which one expects with clinical otosclerosis has not yet appeared.

is to locate the site of damage accurately, to designate definitively the structures involved, and to describe specifically the pathology which is, or has been responsible for the hearing difficulty  Of course, much needs to be learned before full diagnostic precision will become possible here

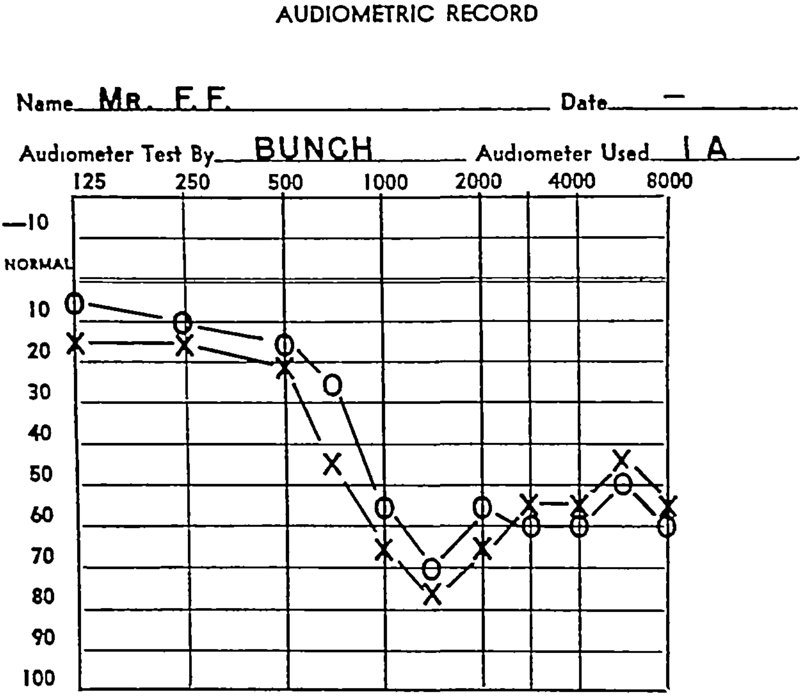
Fortunately, a wide variety of auditory tests directed toward this goal have been developed or adapted in recent years Many of these tests have been of the supra-threshold variety, *i e*, loudness balance techniques, methods for measuring DLs for intensity change, tests of speech discrimination in quiet and in noise, and the delayed side-tone procedure  It is still too soon to specify the ultimate usefulness of all these techniques, however, their clinical applications are rapidly becoming clarified in consequence of extensive research from different parts of the world  The diagnostician's efficiency has already been enhanced significantly, and future research will bring him added insight

The emphasis on new tests has diverted attention from the contribution which conventional threshold audiometry can make to differential diagnosis among sensori-neural lesions There is no reason to believe that the limits in interpretation of the audiogram have been reached, in fact, critical study of audiometric configurations suggests subdivisions in diagnostic categories which the clinician does not currently consider Clinicians, (and theorists) can profitably re-examine the significance of threshold audiometry

## IX

It would be premature to attempt a systematic description of the array of clues to differential diagnosis which are available through plotting thresholds for pure tones  One can, however, illustrate the existence of such clues by discussing examples involving sensori-neural losses  These examples consist of audiometric pecularities which are easily recognized, but which still await full interpretation

One example is the configuration of sensori-neural loss wherein acuity for low frequencies is near normal, and wherein there is sharp transition to a plateau of high frequency loss at about 60 db This type of impairment is relatively common, and its existence can be demonstrated either from contemporary clinical records or from the literature Figs 6 and 7 are samples of this configuration taken from Bunch's original records, which are preserved at Northwestern University Fig 8 plots a similar impairment, as found in a


AUDIOMETRIC RECORD

Name MR. F.F. Date —

Audiometer Test By BUNCH Audiometer Used I A

Fig 6 Hearing levels for air conduction exhibited by 44-year-old man employed as a riveter

case tested at Northwestern in 1957 These three exemplify an audiometric feature which is quite common, even though it does not repeat itself with perfect consistency from one patient to the next The existence of a distinctive type of lesion can be postulated from the fact that so many high frequency losses plateau at approximately the 60 db level of loss This lesion must be of such nature that it does not interfere with acuity for low tones, nor with response to intense sounds at high frequencies One can not help but speculate that this lesion may be geographically restricted, so that neural representation from the outer hair-cells within the basal region of the cochlear spiral is lost, while excitation from the inner hair-cells within the same region continues to have central representation, as does excitation from the more apically located hair-cells of both varieties Minor differences in the extent, the severity, and the purity of the lesion could account for the clinical variations observed in hearing losses of this general type

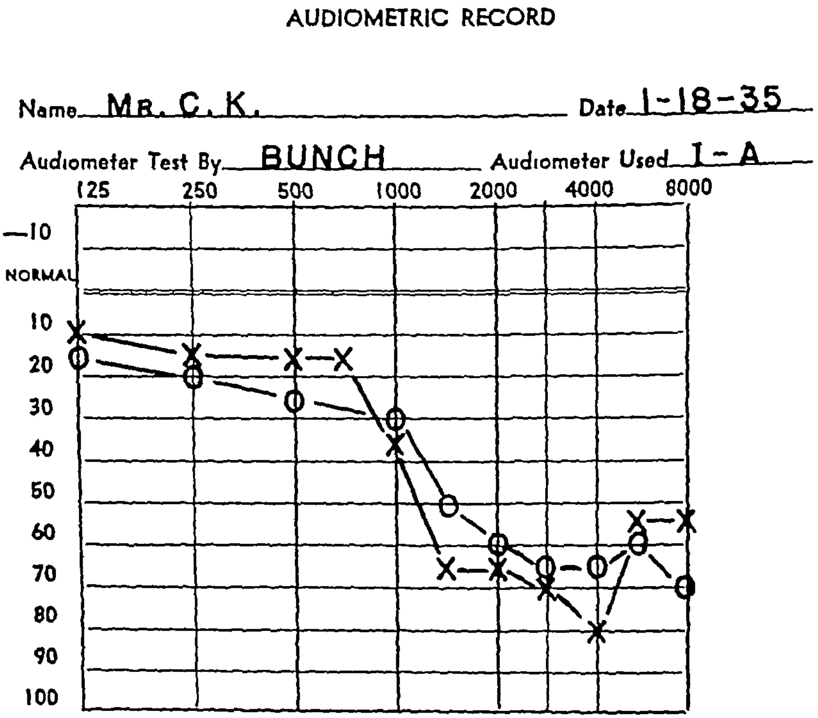


Fig 7 Hearing levels for air conduction exhibited by a 25-year-old man with sensori-neural involvement of unspecified etiology

The foregoing speculation does not require the presumption that the outer hair-cells have been destroyed, although such a situation is one possibility An equally tenable alternative is the possibility that the innervation from these hair-cells to the central nervous system is defective There may, moreover, be other alternatives, and subsequent study may reveal that several types of lesion produce the audiometric configuration under discussion

The idea being stressed at the moment is that this unique audiometric configuration must result from patterns of lesion which are distinctive  It is convenient, since the external

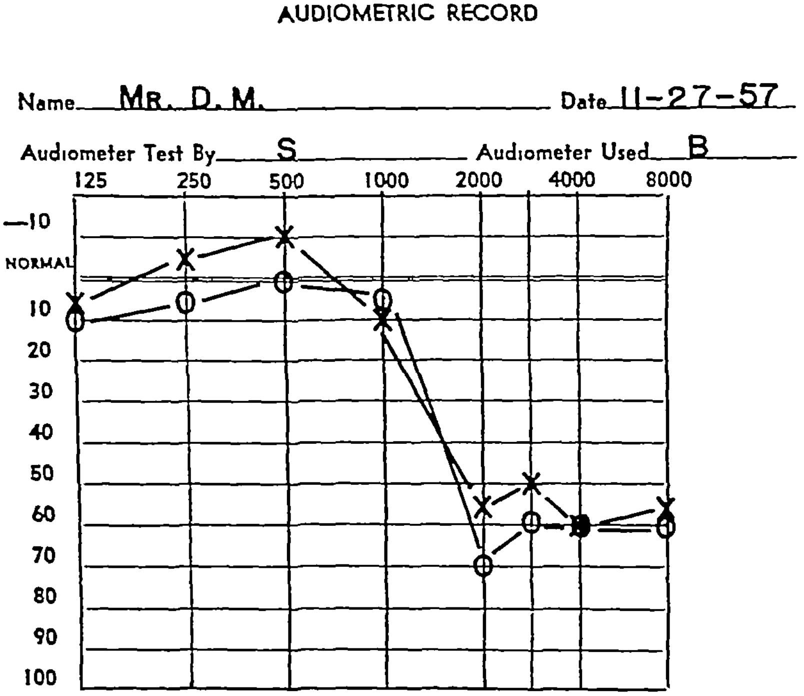


Fig 8 Hearing levels for air conduction exhibited by a 59-year-old woman with bilateral sensori-neural involvement of unknown etiology

hair-cells are thought to mediate response to weak stimuli and are more susceptible to damage from intense stimulation,[6] to evoke the speculations advanced in the preceding paragraph, however, these speculations are not essential in the present discussion  They merely illustrate the kind of thinking which study of threshold audiograms excites  The fundamental premise, which neither clinician nor theorist dare ignore, is that every hearing loss is the product of a specific set of lesions These lesions determine the nature of the audiometric configuration which the patient exhibits The fact that diverse patterns of pure tone loss are encountered indicates that auditory lesions differ not only in extent but also in kind One way in which clinical audiology can participate in classifying the conditions involved is by renewing its interests in the details of audiometric configuration One practical benefit will be that the diagnostic usefulness of conventional audiometry will increase

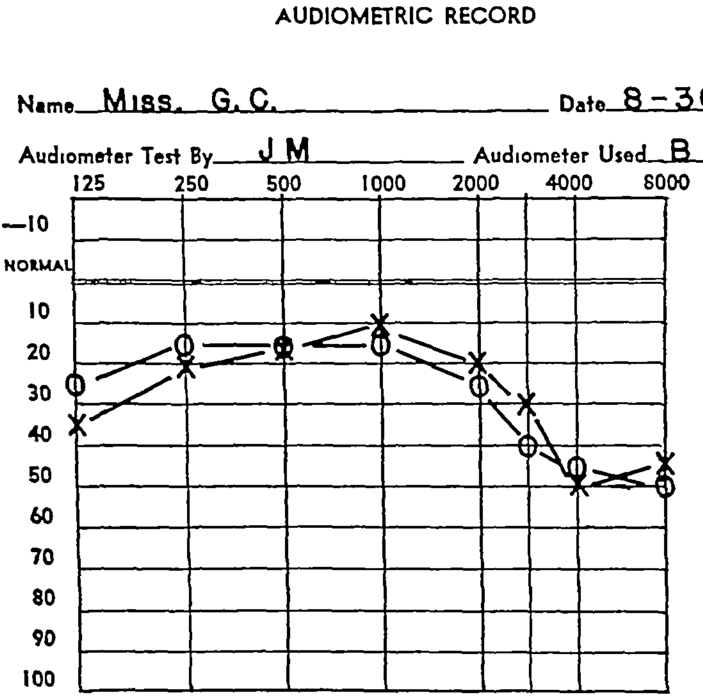
## X

Consider two additional illustrations of the diversity of information which the pure tone audiogram can contain Both illustrations involve peculiarities of auditory function frequently found in conjunction with presbycusis

One of these peculiarities is exemplified in Fig 9 Note that here the loss exhibited at 125 c p s is greater than at 250 c p s This configuration has been observed as a group trend in various studies where general populations of elderly people have been sampled [4, 12] It also appears as a clearly identifiable feature in the audiograms of many clinical cases, who sometimes yield thresholds 15 db poorer at 125 c p s than at 250 c p s

Such findings are baffling if one attempts to account for them on the basis of peripheral lesions in the sensori-neural mechanism of the ear In other words, the peripheral degeneration of hair cells and spiral ganglion cells, which has been observed to characterize presbycusis,[18] cannot account for the increased loss at 125 c p s This degeneration affects the sensori-neural structures serving the basal region of the cochlea It consequently disturbs acuity for higher frequencies Any effect it may have at 125 c p s should not be more severe than the effect at 250 c p s , moreover, these two latter frequencies are within the range which cochlear agitation is diffuse and where, stated in general terms, the same structures will be stimulated by both stimuli Thus, since volleys of neural impulses are the intermediaries to perception of low frequency tones, the distinction within the auditory system between a tone of 125 c p s and one of 250 c.p s is a difference in the rate at which the volleys are triggered

It seems reasonable to conclude that many elderly persons who retain equivalent peripheral sensitivity at these two frequencies require a greater comparative intensity in order for


AUDIOMETRIC RECORD

Name Miss. G. C. Date 8-30-57

Audiometer Test By J M Audiometer Used B

Fig 9 Hearing levels for air conduction exhibited by an 80-year-old woman having presbycusis This chart exemplifies cases with greater loss at 125 c.p s than at 250 c p s

stimulus to be perceived when the volley rate is 125 per second, than when it is 250 per second * In such event, the extra impairment in acuity found at 125 c p s must depend upon a disturbance of function within the central nervous

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*The alternative would be that the ageing of structures within the inner ear changes the mechanical constants of the auditory system in such manner that its responsiveness to very low frequencies is differentially impaired This possibility seems a less likely source for the phenomenon under discussion.

system It would be foolhardy to speculate regarding the site or the nature of such malfunction, however, because such a disturbance could disrupt various facets of auditory behavior[1, 17] and hence complicate a patient's problem, the clinician must be alert to the potentiality that it may be present in a particular case Proper attention to the audiometric configuration can warn the clinician of this potentiality

A second peculiarity in the auditory response of some elderly patients is an abnormally great loss by bone conduction at 500 c p s This phenomenon was identified by Bernero, who noted it in the records of the Hearing Clinics at Northwestern University The audiometric technique employed in these Clinics is one wherein masking is not used routinely while testing bone conduction Masking is introduced only when the patient states that his auditory experience is not localized to the ear under test This fact is mentioned because, as described below, it appears to be an important condition in evoking the Bernero phenomenon

A typical example of the phenomenon is reproduced in Fig 10, which gives results for only one ear The agreement between air and bone thresholds is good except at 500 c p s Tradition would lead one to discount the difference at 500 c p s as being due to testing error, however, this particular discrepancy is observed so repeatedly that it can not be dismissed in a cavalier fashion, and one can not ignore evidence such as the observation by Ciocco,[5] reported in 1934, that elderly persons have disproportionately reduced acuity by bone conduction when tested with the 512 c p s tuning fork, therefore, the clinician is justified in suspecting that he is encountering the Bernero phenomenon when the patient is elderly, when the bone conduction threshold of 500 c p s is 10 to 15 db poorer than the air conduction threshold, and when the remainder of the audiogram shows the close correspondence between measures to be expected in sensori-neural loss

The Bernero phenomenon cannot be explained by conventional principles of audiometric interpretation These principles specify that loss is less for bone than for air when the impairment is of the conductive variety, whereas the two losses are equal when the lesion is a sensori-neural one Only in rare instances of skull anomaly, such as Guild has described,[8] could gross mechanical factors account for excessive loss by bone, and here the effect should not be limited to one frequency, thus, only two alternatives remain

AUDIOMETRIC RECORD

Name Mr. C.P. Date 10-10-48

Audiometer Test By C H Audiometer Used I

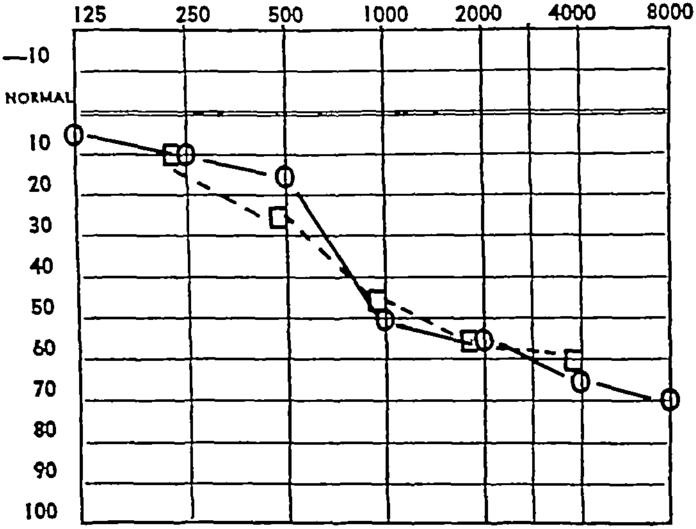

Fig 10 Hearing levels for the right ear of a 71-year-old man having presbycusis This chart illustrates cases with noticeably greater loss at 500 c.p.s by bone conduction than by air conduction

One possibility is that ageing has modified the mechanical constants within the inner ear in such a manner that a differential reduction in the responsiveness of the auditory system of skull-borne vibration at 500 c p s has been produced This possibility seems relatively unlikely, even though some writers have postulated that ageing sometimes produces a conductive loss within the inner ear in consequence of the physical changes that occur there system. It would be foolhardy to speculate regarding the site or the nature of such malfunction, however, because such a disturbance could disrupt various facets of auditory behavior[1,17] and hence complicate a patient's problem, the clinician must be alert to the potentiality that it may be present in a particular case. Proper attention to the audiometric configuration can warn the clinician of this potentiality.

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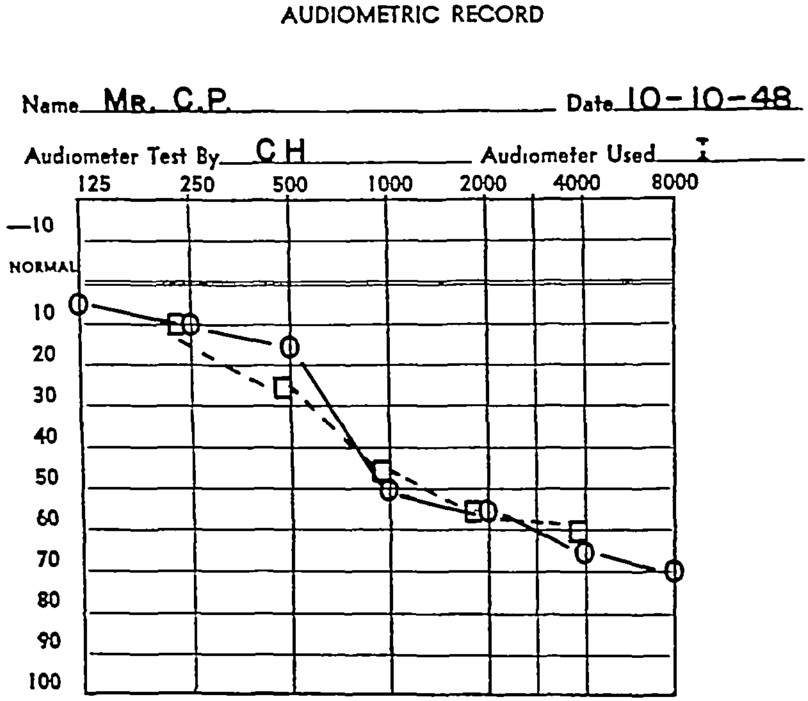

AUDIOMETRIC RECORD

Name MR. C.P. Date 10-10-48

Audiometer Test By C H Audiometer Used I

Fig 10 Hearing levels for the right ear of a 71-year-old man having presbycusis. This chart illustrates cases with noticeably greater loss at 500 c.p.s. by bone conduction than by air conduction.

One possibility is that ageing has modified the mechanical constants within the inner ear in such a manner that a differential reduction in the responsiveness of the auditory system of skull-borne vibration at 500 c.p.s. has been produced. This possibility seems relatively unlikely, even though some writers have postulated that ageing sometimes produces a conductive loss within the inner ear in consequence of the physical changes that occur there.

The alternate possibility is that the Bernero phenomenon appears whenever the bone conduction stimulus is more difficult to perceive than is the air conduction stimulus This alternative presumes that peripheral sensitivity is the same for the two modalities, but that a functional peculiarity is operative which makes conscious recognition of the bone conduction stimulus at 500 c p s difficult A potential mechanism comes to mind quickly One need merely remember three facts *1* in presbycusis the two ears usually exhibit bilateral symmetry of loss, *2* when such bilateral symmetry exists the air conduction stimulus activates only the ear under test, so that monaural excitation occurs at threshold, *3* the bone conduction stimulus reaches both cochleas Such a stimulus should excite both ears if they are similar in sensitivity and neither is masked True, the levels of stimulation will seldom be identical, and the experience of hearing will ordinarily localize to one ear or the other

Bilateral excitation by bone goes unnoticed in most clinical circumstances, however, it may be a critical consideration when perceptual abilities are reduced, albeit subtly, by age Stated differently, the foregoing considerations lead one to interpret the Bernero phenomenon as indicating a condition wherein the cortical differentiation of two trains of neural impulses is more difficult when the impulse rate is 500 per second, than is the differentiation of a single train, and one must presume, since the phenomenon is restricted to 500 c p s, that this disadvantage in bilateral hearing is not apparent when the stimulus frequency is either markedly lower or markedly higher in frequency The reasons for such a circumscribed disturbance in perception are obscure, but its existence cannot be ignored Thus, it would seem that the Bernero phenomenon is a clue to a central perceptual disturbance As such, it is a second audiometric aid to the identification of those elderly persons whose hearing difficulties are not exclusively of peripheral origin

## XI

A point worthy of re-emphasis is the fact that understanding of auditory abnormalities is currently imperfect Both the clinician and the theorist must remember that there are aberrations in hearing function which the usual testing procedures do not reveal  The diagnostic significance of such aberrations will emerge as the aberrations become known and understood  One result will be further insight into the meanings which can be assigned to results of conventional audiometry

Consider the phenomenon of abnormal auditory adaptation as it is revealed through the tone decay test[3]  The procedure is to present a sustained pure tone at threshold for a full minute unless the patient signals that the tone has become inaudible  In the latter event, the intensity is increased 5 db , and the timing is started anew  This routine is repeated until an intensity is found at which the tone remains audible for 60 seconds  The exploration is then complete at this frequency, and a new exploration may be started at another frequency

Results for the tone decay tests are classifiable into three general categories  Cases with conductive loss, and some with sensori-neural impairments, do not reveal auditory adaptation at threshold  Other cases of sensori-neural loss exhibit moderate adaptation for high frequency tones, *i e* , up to 25 db drift in the level at which the tone remains audible  Adaptation for low frequencies is rare  Finally, occasional instances occur in which adaptation is so extreme that the tone is heard for a full minute only at great intensities, or else not at all  This extreme type of adaptation has been encountered both in cases where there is hearing loss in the ordinary sense, and in instances where standard audiometry yields normal thresholds  Such findings indicate unusual auditory disturbances  Tentatively, it appeared that adaptation as extreme as this is the result of a neural lesion,[18 10] while moderate adaptation probably has its origin in the cochlea[9]  It would seem, moreover, that not all types of disturbance in either locus produce abnormal adaptation at threshold, since many sensori-neural losses do not exhibit any tone decay at threshold  This matter will have to be clarified by further research

The foregoing discussion not only illustrates the fact that abnormalities in auditory function are complicated and, hence, emphasizes the need to classify clinical sub-types more adequately It also calls attention to phenomena which must be kept in mind by the clinician as he interprets conventional threshold tests He should, for example, become immediately suspicious that a problem of abnormal adaptation may exist whenever he encounters a subject whose threshold level seems to vary excessively from moment to moment Stated differently, the fact that a patient's audiometric responses are highly unreliable may be a clue to unique features in his hearing loss which can be quantified if explored with an appropriate additional test

## XII

In summary, the pure tone audiogram can be of great help in the differential diagnosis of hearing losses The configuration of the air conduction curve often suggests etiology, and in cases of conductive loss, the nature of the mechanical disturbance In addition, air-borne relationships distinguish conductive from sensori-neural involvements Minor variations in the bone conduction curve are characteristic of different conductive lesions Finally, threshold audiograms contain much information which awaits full codification and which, when so codified, will contribute to a new level of precision in differential diagnosis among hearing losses

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**Dr. Hirsh** We have time for a question

**Dr. Moe Bergman** (New York, N Y) I would like to express my own gratification as I am sure the whole group does Professor Carhart is continually urging us to go back and look at our audiograms very carefully

I would like to ask a question on that last slide, and that is on that very provocative case of tone decay I wonder, again, whether there is a relationship between the recruitment and the loss of loudness in the better ear as against the growth of loudness in the worse ear. Is the recruitment due to a growth of loudness in the poor ear, therefore, giving us equal loudness, or because of the decay in the better ear?

**Dr. Carhart** There might be just the reverse. The better ear has such a low level of loudness that the match is made close to threshold even though there is no recruitment, in the conventional sense, in the better ear.

These questions which you raise are very exciting and represent part of the speculation which ought to be done I can simply report to you facts In elderly people, at least, I am convinced that this phenomenon of poor hearing, 125 and 250, is sufficiently frequent so that it cannot be accounted for on mechanical ground or some immediately explainable ground which we might think of, since we do not find it simultaneously in the same clinical run, so to speak, on cases that do not fall in this category

DR HIRSH The first question had to do with physical factors that make the measurement of 125 unreliable

DR. CARHART I thought I answered that simply by stating that this is an observation made under clinical circumstances where other types of cases did not seem to show unreliable responses to 125

DR TAUNO PALVA, (Turku, Finland) I should like to comment on certain aspects of Dr Carhart's paper, although I am supposed to discuss some of these phenomena in my own presentation to be given later

The last slide shown by Dr Carhart described a very large stimulatory adaptation loss during only some thirty or forty decibels of stimulation What is even more remarkable is that there was similar fatigue in the healthy ear as in the deaf ear If the result is real, I think it is an extreme variant I have made a continuous threshold recording during four minutes stimulation in over two hundred cases, representing mostly recording perceptive type of lesions, but I have never seen as severe per-stimulatory fatigue as described by Dr Carhart

In my experience the threshold sensitivity loss does not generally exceed 30 to 40 db, and it does not occur in more than 15 to 20 per cent of the patients with perceptive lesions

My second point concerns the slight loss of bone conduction observed by Dr Carhart at higher frequencies in certain cases with chronic ears Supposing that some of these ears had perforations in the tympanic membrane with dry cavity, I should like to know whether bone conduction measurements were also made when the tympanic perforation was closed, for instance, with a cigarette paper patch The possible difference in the open and closed perforation could tell us whether the slight bone conduction loss was due only to the altered conductive ability of the tympanic membrane or whether there were also changes in the window nucleus that could be responsible for a covered bone conduction

DR. CARHART I would not wish to attempt to state what particular kind of mechanical factor might be responsible for the type of thing I was talking about in the bone conduction test

I will comment briefly on the first point you made, Dr Palva This particular kind of a test is a sort of first inventory, of course, and this particular case, while it is extremely unusual, and I suppose, for that reason makes a beautiful demonstration, is nonetheless one whose validity, whose clinical reality I cannot doubt, because the person who did this happened to be a Danish physician who was working with us at the time, and who did not believe the results of the test the first time and, therefore, returned and repeated the test and got the same results the second time

DR. HIRSH Our discussion of audiometry has begun with the role of the audiogram, which is, as Dr Carhart told you, useful, and in addition, the pure tone adaptation test which Dr Carhart has implied will be useful in the future

Let us return now to a consideration of a very important set of problems surrounding the syndrome known as Ménière's disease

## MENIERE'S DISEASE

THEODORE E WALSH,

St Louis, Mo

I would like to bring up one point first about audiology in the diagnosis of Ménière's disease I find the audiologist is quite a help, but I would emphasize that the diagnosis is made by clinical observation I am not being facetious, I just want to emphasize the point that it is a careful history of the case and a careful observation of the patient by which the diagnosis of Ménière's disease is made The audiologic findings simply confirm the diagnosis

Let us first take up the symptoms of Ménière's disease Patients with this disease usually seek help because they are dizzy It is usually not difficult to determine whether this dizziness is truly vestibular in origin or whether the so-called dizziness is not related in any way to the labyrinth Although the main complaint is directed at the vestibular symptoms, it is really cochlear dysfunction which is responsible for the condition I emphasize the point that I believe Ménière's disease is primarily a cochlear disease

In taking a careful history of patients one can usually determine that they noticed some loss of hearing before they ever had their dizzy spells Patients seeking help for Menière's disease not only complain of dizziness but they also notice deafness, and they complain bitterly of tinnitus

Now to discuss these symptoms individually, first, tinnitus The most common description given of this tinnitus is that it sounds exactly like the noise heard when listening into a seashell, or the sound of the roar of the surf breaking on the seashore Those individuals who have never been fortunate enough to listen into a seashell or hear the surf, will tell you that the sound they hear in their ear resembles the roar of a high wind in a forest or sometimes the sort of sound one hears when listening close to a telephone pole in a high wind The patients also complain of a full feeling in the head which cannot be described in any other way except that it is a full feeling The hearing fluctuates At times these patients say they hear "perfectly" and at other times "nothing at all," but, on careful questioning about the hearing, most of them say they can hear but they do not understand This ability to hear and not understand is easily demonstrated when talking to these people One seldom has to raise one's voice in talking to a patient with Ménière's disease even if he is in a period of "hearing nothing at all," but one must talk very slowly and very distinctly

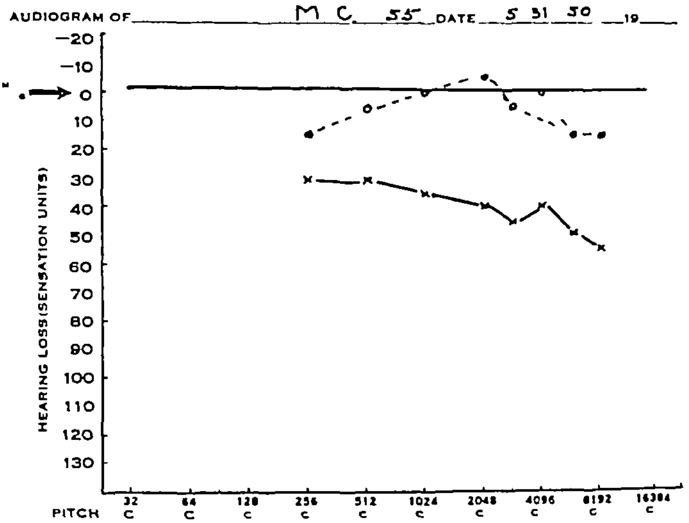
Another complaint, which is more noticeable in musical people, is that of a different sensation of sound in the two ears, diplacusis. This is very common. If the patient is not musical he will tell you that sounds are different in the two ears, and he describes the sound in the worse ear as fuzzy. In the office we test for this diplacusis by the use of tuning forks, and I would emphasize that it is important to test with all forks throughout the whole range, because diplacusis may not be present at every tone. Frequently they notice no difference, for example, with a 500 cycle fork whereas when one uses the 4000 cycle fork it sounds different in the two ears and vice versa.

The vestibular tests are on the whole not much help in making a diagnosis of Menière's disease. We may find a normal response in the two labyrinths, we may find a canal paresis in the affected ear, or we may find a directional preponderance, first to the affected side and later to the normal side. It depends a good deal on how long the condition has been present as to what vestibular findings will be. Now I would like to show some slides that illustrate these various points, the important points in the audiology of Ménière's disease.

Fig 1—In this you see the pure tone audiograms of the two ears, one ear being perfectly normal and the other one not. This is not a very common pure tone curve in early Ménière's disease. As a rule the pure tone audiogram shows a greater loss in the low tones and almost no loss in the high tones in the early cases, and later the curve flattens and there is an equal loss throughout the scale, still later more and more of the high tones are lost as well as the low, so that one has a down-sloping curve.

Diplacusis is well shown in this individual, and you notice that the 500 cycle tone is matched fairly closely, but at 4000 cycles he matches it with 2890. I always feel sorry for people with that sort of diplacusis. It must be incredibly difficult to live with, if one is musical.

One of the points I mentioned, in our office examination, that these individuals had not much loss for speech at thresh-



DIPLACUSIS TESTS

| REFERENCE EAR<br>LEFT | MATCHED EAR<br>R AUT |
|---|---|
| 500 cps | 440 cps |
| 1000 cps | 950 cps |
| 2000 cps | 1880 cps |
| 4000 cps | 2890 cps |

| | LEFT | RIGHT |
|---|---|---|
| *9 | 2 | 39 |
| PB | 84% at 90<br>80% at 100 | 30% at 110<br>36% at 100 |

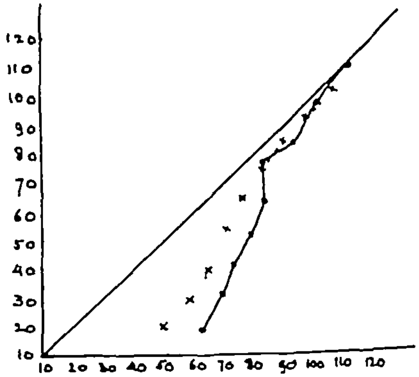


Fig 1

old but considerable difficulty with discrimination, and this is shown here I would like to emphasize this point, because in going through a considerable number of these cases I found in no instance was the discrimination score better than 50 per cent, whereas the threshold was seldom more than a 40 decibel loss

Figure 2 illustrates much the same thing In this individual the fluctuation in hearing is well shown I would like to emphasize this fluctuation in hearing because it makes it very difficult for us, as clinicians, to determine whether any therapy we use is really doing any good unless we can follow the patient over a considerable period of time This particular individual was under treatment during the time between December, 1950, and February, 1951, and it will be seen that his hearing was different on three different occasions Here, in January, 1951, he has a normal hearing for speech, whereas in February, in spite of therapy, he drops to a 40 per cent discrimination score and a 29 decibel threshold loss

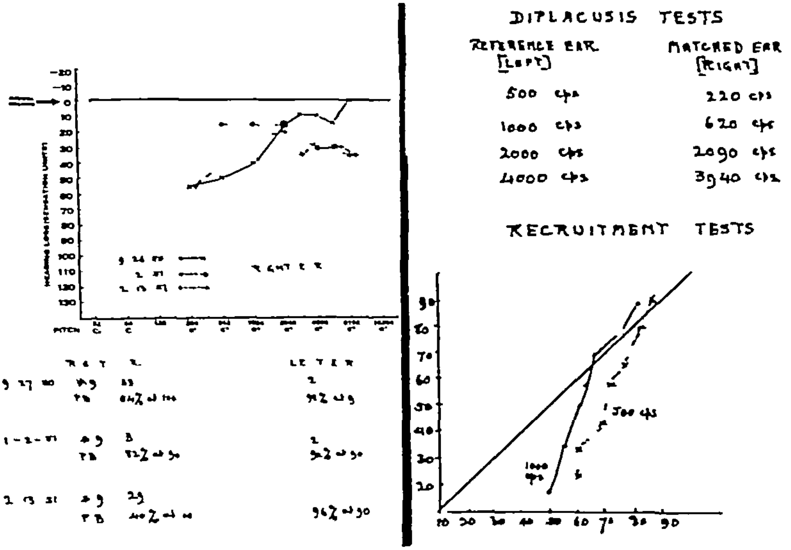


Fig 2

Figure 2 also shows the same patient's recruitment and the diplacusis In this instance, he had a considerable difference in the hearing for low tones rather than in the high

Now the fluctuation in hearing, I think, is important It is very important to start therapy in these individuals when the hearing is fluctuating, because it seems to me that that is when there is a chance of saving some hearing and really rehabilitating these individuals It is true that the treatment of Ménière's disease is directed first toward the relief of the unpleasant and dangerous vertigo Unfortunately, that is

| | Right | | | | | | | | Left | | | | | | | | Speech | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | Right | | Left | |
| Date | 256 | 512 | 1024 | 2048 | 2896 | 4096 | 5792 | 8192 | 256 | 512 | 1024 | 2048 | 2896 | 4096 | 5792 | 8192 | T L | Dis | T L | Dis |
| 12/1/55 | 45 | 55 | 65 | 50 | 50 | 60 | / | / | 25 | 30 | 15 | 10 | 45 | 50 | 65 | 60 | 85 | 6% | 16 | 80% |
| 12/29/55 | 40 | 50 | 60 | 35 | 50 | 65 | / | / | 30 | 40 | 40 | 25 | 50 | 55 | 60 | 65 | | | | |
| 1/9/56 | 30 | 35 | 35 | 30 | 55 | 65 | / | / | 45 | 40 | 45 | 20 | 50 | 55 | 65 | 60 | 27 | 32% | 29 | 54% |
| 2/6/56 | 25 | 30 | 25 | 15 | 40 | 65 | / | / | 30 | 45 | 50 | 30 | 50 | 55 | 65 | 60 | 15 | 64% | 43 | 24% |
| 2/20/56 | -- | | | | | | | | | | | --- | -- | -- | -- | | 16 | 72% | 30 | 50% |
| 3/5/56 | 25 | 30 | 20 | 15 | 45 | 65 | / | / | 20 | 5 | 15 | 20 | 50 | 55 | 65 | 60 | 12 | 66% | 0 | 80% |

The meaning of the abbreviations is as follows T L threshold loss Dis discrimination

Fig 3

where it usually stops As a matter of fact, I don't believe that the relief of vertigo is nearly so difficult as the preservation of hearing That this preservation is possible by treatment I would like to show in Figure 3

This is a man who has a bilateral Ménière's disease You can see that his hearing in both ears is fluctuating considerably but on treatment he has remained at this good level for quite some time

Figure 4 illustrates the same sort of fluctuation This is an old man with presbycusis in one ear and Ménière's disease in the other When we started therapy the hearing in the ear with Menière's disease had only 28 per cent discrimination, but on treatment it went up to 76 per cent, and his threshold also improved When the medication was changed his hearing dropped, but we have been able now to preserve him at a level of some 70 per cent discrimination for several years

To summarize the audiologic findings, the important ones are *1* Fluctuation in the hearing which gradually becomes worse until almost complete deafness results *2* The loss at threshold for speech is not great in comparison with the discrimination loss *3* Early pure tone audiograms show an up-sloping curve and later the curve flattens and finally the high tones are lost *4* Diplacusis is almost always present *5* The tinnitus is described as a roaring sound and there is a full feeling in the ear *6* Finally, the most important point in the differential diagnosis of Ménière's disease is the invariable presence of recruitment that even becomes in some instances hyper-recruitment

DR HIRSH Are there any comments?

UNIDENTIFIED DOCTOR I would like to comment on diplacusis which is observed in many cases In effect, the diplacusis may sometimes make very difficult the evaluation of the other ear, which is very useful for diagnostic purposes, and I should like also to stress that in my opinion it is not always easy to make a pure audiological diagnosis

| | Right | | | | | | | | Left | | | | | | | | Speech | | | |
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| Date | 256 | 512 | 1024 | 2048 | 2896 | 4096 | 5792 | 8192 | 256 | 512 | 1024 | 2048 | 2896 | 4096 | 5792 | 8192 | T L | Dis | T L | Dis |
| 2/19/53 | 0 | 0 | 0 | 15 | 30 | 35 | 25 | 25 | 25 | 20 | 10 | 45 | 50 | 40 | 65 | 45 | -- | -- | | |
| 3/25/53 | 0 | 0 | 0 | 30 | 45 | 50 | 50 | 55 | 50 | 35 | 45 | 35 | 45 | 50 | 50 | 45 | | | | |
| 5/5/53 | 0 | 0 | 0 | 45 | 55 | 55 | 55 | 60 | 45 | 35 | 30 | 25 | 45 | 45 | 55 | 35 | 11 | 66% | 42 | 28% |
| 2/9/54 | 0 | 0 | –5 | 40 | 55 | 55 | 60 | 60 | 20 | 25 | 10 | 15 | 40 | 45 | 55 | 40 | 5 | 60% | 16 | 76% |
| 2/1/55 | –5 | –5 | 0 | 35 | 50 | 55 | 50 | 55 | 30 | 35 | 35 | 10 | 45 | 45 | 55 | 40 | 8 | 68% | 28 | 72% |
| 10/18/55 | | | | | | | | -- | | | | | --- | --- | -- | | 6 | 70% | 30 | 54% |
| 12/13/55 | | | --- | | | | | --- | | | | | | | | | 6 | 64% | 31 | 56% |
| 2/7/56 | | | | -- | | | | --- | | | | | | | | | 3 | 70% | 27 | 60% |

The meaning of the abbreviations is as follows T L. threshold loss Dis discrimination

Fig 4

of Menière's disease. We have several diseases characterized by vertigo which are not Menière's disease, but are due to some disease of the nerves, for instance, the fact of a patient having vertigo and practically normal hearing. This could be an unusual case of Ménière's disease without impairment of the auditory function, but we could not do without the vestibular examination in all cases of Ménière's disease because it not only informs us about the condition of the vestibular apparatus, but also adds very much to our diagnosis. In effect, if you find a man who has vertigo and normal hearing and you send him to the audiologist who says that he finds a total loss—we are clearly dealing, not with a Menière's disease but with a neuritis of the acoustic nerve, because in Menière's disease it is impossible to have a total loss of function of the vestibular apparatus. On the other hand, we have total loss of hearing or a severe loss of hearing with a fairly normal vestibular nerve. Now, this is generally due to the fact that we are dealing with a cochlear neuritis. In fact, we might rely on some combinations of cochlear and vestibular diagnostic testing. If we have a total loss of hearing and a total loss of vestibular function on one side, we may, likewise, make a diagnosis of neuritis of the VIIIth nerve, and in the history of the patient we never discover any sign of even the slightest vertigo. We are confronted in this case with a tumor of the acoustic nerve. It is my opinion that no diagnosis of Menière's disease should be made unless the vestibular examination and the cochlear examination agree as to their results. The results must go hand in hand, otherwise we are not certain that we are dealing with a Ménière's disease and not with an infection of the head nerves.

DR. VICTOR GOODHILL: I fully agree with Dr. Walsh that tinnitus may be the consideration that he described in Menière's disease, however, I have seen this type of tinnitus in otosclerosis not too rarely, and in other lesions, which prompts me to urge my audiological colleagues here today to give more attention to tinnitus analysis in the overall approach to diseases of the ear. I think we have neglected the symptom of tinnitus, and that can help us a great deal if we set out to get some technique for clinical attention, qualitatively and quantitatively.

# COCHLEAR VS RETROCOCHLEAR LESIONS

TAUNO PALVA,
University of Turku,
Turku, Finland

It is a general rule that the major division between hearing disorders of conductive and perceptive type is made on the basis of a pure tone audiogram If bone conduction is normal or clearly better than air conduction, the case is labeled as conductive, if it equals or is poorer than air conduction, the deafness is classified as perceptive The first conclusion always holds true In the latter case, classification is not so simple, therefore I feel that, before discussing the differences in the subgroups of perceptive deafness, it is necessary to say a few words about cases where air conduction approaches or equals bone conduction, though there is a purely conductive deafness

Together with Ojala,[1] I have pointed out that in nearly one-third of the cases with simple acute otitis media, bone conduction is abnormally poor as long as the middle ear has not healed In these cases, however, the diagnosis can be ascertained simply by looking at the tympanic membrane, but diagnosis is no longer so easy in cases of serous or adhesive otitis generally associated with only minor alterations in the tympanic membranes These cases present a typical curve of perceptive component with lowered bone conduction, most severely at the higher end of the scale The reason for this is either serous secretion which fills the window niches and the middle ear, or adhesions and thickened mucous membranes which fix both windows In the absence of inflammation both air and bone conduction instantly return to nearly normal values when the serous fluid is aspirated

Otoscopic examination with Siegle's speculum and aspiration of the middle ear are the most important assets in separating these cases from true perceptive deafness In rare cases even exploration of the middle ear may be necessary to obtain a correct diagnosis and to return good hearing

If it is established that the middle ear is normal, equal air and bone conduction indicate perceptive deafness In the large majority of cases the lesion is localized to the end-organ or to the VIIIth nerve, only a few cases present a more central pathology

*Recruitment Testing*

In dividing perceptive deafness into these two main subgroups, it has been customary to use the recruitment of loudness as a criterion Fowler's[2] original concept was that this phenomenon occurs in perceptive deafness in general, and is not typical of any more definitely localized lesion Tests of loudness recruitment have enjoyed increasing popularity only since 1948 when Dix, Hallpike and Hood[3] stated that recruitment is pathognomonic of end-organ disease, more specifically of lesions in the hair cells

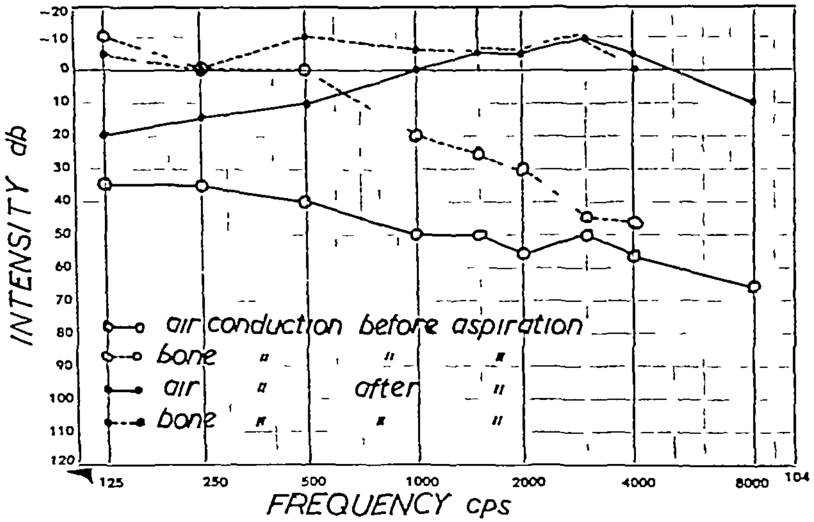

Fig 1 A case with serous otitis media. Bone conduction is considerably lowered at higher frequencies but returns promptly to normal after aspiration of the middle ear

The first histological correlation of loudness recruitment to the changes in the end-organ was obtained from cases of

Ménière's disease where the special feature, agreed upon by all investigators, was distension of the cochlear duct Special damage to the hair cells was observed by Hallpike and Cairns[4] and by Dix and Hallpike[5] in a total of three ears Other workers,[6-8] however, were not able to find such hair cell changes as could be definitely separated from postmortem degeneration On the other hand, it was common observation that ganglion cells and nerve fibers remained intact at least in the earlier part of this disease, and thus the presence of recruitment must necessarily be related to the structures peripheral to the spiral ganglion

Another histological correlation comes from the animal studies of artificial acoustic trauma[9-11] It is agreed that the lesions are primarily seen in the mesothelial cells of the tympanic lamella and in the external hair cells Following very intense stimulation the whole organ of Corti may be destroyed The lesion is also evidenced by a marked reduction of the cochlear potentials, although such a reduction may occur in ears without demonstrable histological trauma

In human material, exposed to acoustic trauma, the resulting lesions regularly exhibit recruitment phenomenon This is the case in experimentally induced hearing losses by stimulation with intense sounds[13] and in the ears subjected to occupational acoustic trauma[14]

The third histological correlation is derived from Saxen's studies of presbycusis[15] Among his 44 cases there were 13 in which the lesion was restricted to the spiral ganglion and nerve fibers and the end-organ itself was intact Another main group comprised 19 persons in which there were severe angiosclerotic changes in the stria vascularis and high grade degeneration of the organ of Corti, especially in the external hair cells, but sometimes the sensory structure as a whole was degenerated in certain areas As a rule some reduction in the spiral ganglion cells and in the number of nerve fibers also occurred in these cases In this angiosclerotic group Saxén obtained anomalous results with high intensity Weber tuning fork tests lateralization to the ear showing greater changes in the organ of Corti At the time of Saxén's clinical investigation little was known about the recruitment phenomenon, but we now know that this type of result of a Weber test is one way to demonstrate recruitment phenomenon[16]

The presence of recruitment in part of the presbycusis cases is easily demonstrated with the monaural loudness balance test Pestalozza and Shore[17] reported complete recruitment in four cases out of 20 studied It is also the experience at our laboratory that many presbycusis ears show recruitment

We must now consider closely the group of neural deafness showing prominent lesions in the nerve fibers and also in the spiral ganglion, *viz* acoustic neurinomas Dix, Hallpike and Hood,[3] who first described this group as typical nonrecruiting deafness, later[18] found recruitment of loudness in 12 per cent of the tumors Even earlier, defending his theory that the recruitment phenomenon is typical of perceptive lesions in general, Fowler[19] described one case with complete recruitment I have recently seen a case of cerebellopontine angle lesion with recruitment The explanation for recruitment in these typical neural lesions has been assumed to lie in the disturbed cochlear blood supply, which adds end-organ damage to the picture Dix and Hood[18] even described two cases in which there was recruitment prior to operation when the cochlear blood supply had presumably returned to normal

In the presbycusis group of Saxén,[15] showing only spiral ganglion cell and nerve fiber atrophy, the clinical evaluation showed no evidence of the presence of recruitment

Evidently one can safely say that, if there is recruitment, there is also an end-organ lesion, and that in a pure ganglion cell nerve fiber atrophy there is no recruitment, but there remain a number of cases in which both lesions are combined and recruitment may or may not be present It is probable that if the end-organ lesion dominates, but is not too severe, there is recruitment, and if the neural lesion dominates, there is none When these conclusions are applied to the audiological findings, we must say that positive recruitment is evidence of an end-organ lesion, but does not necessarily exclude an associated neural involvement Contrariwise, the absence of recruitment means that there is a dominating neural lesion but it does not exclude a simultaneous end-organ damage

At present we do not exactly know why recruitment occurs in end-organ lesions, although many hypotheses have been advanced to explain the phenomenon  It is commonly believed that as the excitation becomes stronger, more and more hair cells are activated, especially internal hair cells, which are more resistant to damage than the external ones  The resulting initial discharge would then be capable of stimulating a normal amount of nerve fibers, so that a normal loudness sensation results, however, the matter is not so clear as that  If one believes that the cochlear potentials are a fair indicator of the condition of the hair cells and responsible for initiating the nerve impulses in the cochlear nerve endings, one is at a loss to understand the origin of the recruitment phenomenon

In Fig 2, which is reproduced from Wever and Laurence's recent book[20] "Physiological Acoustics," we notice first a normal cochlear potential curve obtained by increasing the stimulus and recording the increase in the potentials  The lower curve describes a similar response from an ear subjected to acoustic trauma, and it shows a constant deviation from the upper curve  If, in this typically recruiting lesion, recruitment were to depend upon the activity of the hair cells in the form of cochlear potentials, the curves should unite at higher intensities instead of showing the present nonrecruiting slope  The results of Davis and his associates[11] suggest, on the other hand, that the maximum response is lowered less than the threshold, and it might be said to represent partial recruitment

At the present state of our knowledge I suggest that the nerve endings around the hair cell bases may possibly be important also in the origin of recruitment, although the idea that the mechanical movements of the basilar membrane might directly stimulate the nerve endings, is not consistent with the present belief, however, many of Saxén's presbycusis case records indicate good hearing even in cases where the hair cells had suffered intensive damage but the nerve endings were intact  Further data on this question are required

*Indirect Recruitment Tests*

A number of other tests have been devised to take the place of loudness balance tests, or some have been claimed to be independently of great clinical significance In this connection I can discuss only briefly some of these tests For a more complete evaluation the reader is referred to an earlier paper [21]

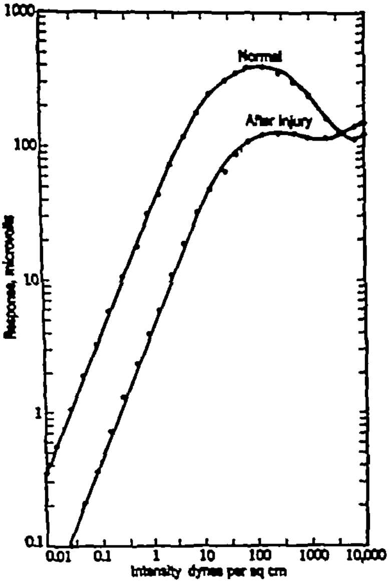

Fig 2 Intensity functions for the cochlear responses of the cat on stimulation with a 1000 c.p s tone before and after injury by overstimulation with this tone Reproduced from 'Physiological Acoustics p 295 by Wever and Laurence [0]

Together with Hirsh and Goodman,[22] I have shown that the tests for intensity difference limen do not differentiate cochlear from retrocochlear lesions the figures for IDL are of the same magnitude for both groups Our testing was done by the method of comparing the intensity of two separate tones, but there is also enough evidence to testify that the use of modulated tones[23 24] does not take us further in the differential diagnosis

The same can be applied to tests for frequency difference limen Some authors[25,26] claim that especially an increased FDL signifies recruiting deafness and cochlear lesions, others say that this very finding is frequent in retrocochlear pathology[27] It is difficult to see how the size of the FDL could be different in these two main categories when one remembers that diplacusis, a change in pitch perception, occurs in cochlear as well as in retrocochlear lesions

Tests for either per- or post-stimulatory fatigue[28-31] have been recommended for differential diagnosis, however, control experiments have shown that abnormal results appear in the two main groups of perceptive deafness, and a large proportion of the cases show results comparable to normal[32,36] We may take as an example continuous threshold recording at a fixed frequency which exemplifies a special kind of per-stimulatory fatigue Hood[28] has claimed that abnormal fatigability in this test is typical of an end-organ lesion, and Reger and Kos,[30] and Kos[37] have reported cases of acoustic tumors with highly fatigable ears at threshold stimulation In my experience[35] a good many cases in both groups show only minor fatigability during a four minute test, but there are cases in both the cochlear and retrocochlear group that show also abnormally high fatigue

The width of the excursions in a self-recording audiometer has also been used as a localizing test in audiometry[38] It seems true that very small excursions, indicating rapid growth in audibility, are a common phenomenon in cases with asymptotic recruitment at higher frequencies At the lower tones, below 1000 c p s, and in the groups of straight or delayed recruitment, the size of the excursions is generally larger and allows no conclusions as to the recruitment phenomenon[35]

Masked audiograms, either with white noise[39] or with saw tooth noise,[40] have also been advocated in the differential diagnosis In control measurements with critically controlled stimuli it has been shown that noise audiometry is not helpful for this purpose[41,42]

*Speech Tests*

During the last decade it has been established beyond doubt that the recruitment phenomenon is accompanied with poor discrimination for speech This has been reported among others by Dix, Hallpike and Hood,[43] by Eby and Williams,[44] by Huizing and Reyntjes,[4] and in our own series [22, 46] Speech function depends mainly upon two facts, *viz* the characteristics of the language and the threshold loss for speech Using the Finnish language, which is rich in vowels, the ability to discriminate is not greatly reduced until the threshold loss exceeds 40 db[46] but using the American PB test this already occurs in cases of 20 db loss [22]

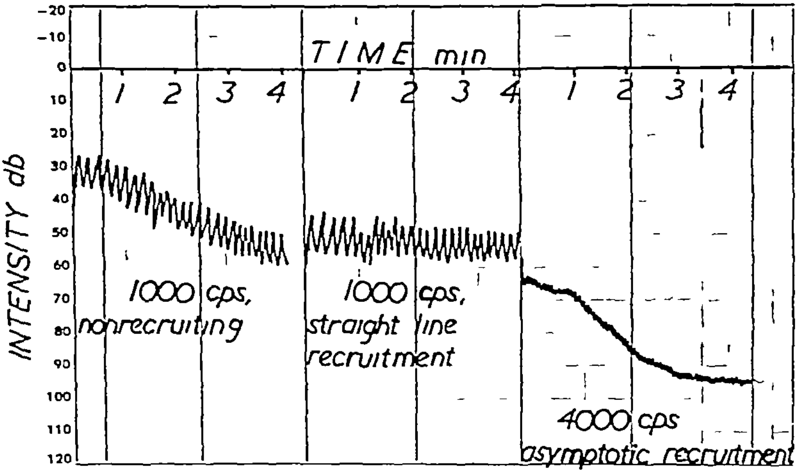

Fig 3 Continuous 4 min threshold recordings in various forms of perceptive deafness Temporary threshold shift may appear in recruiting as well as in nonrecruiting deafness The width of the tracings may remain large also in recruiting deafness especially at lower frequencies.

It was believed at first that in retrocochlear deafness, even when it is severe, speech discrimination is better than in end-organ lesions This was the experience of Dix, Hallpike and Hood[43] and of Eby and Williams[44] in acoustic neurinomas, and at least in the latter series, there were enough data of masking to convince the reader that shadow hearing was not present The ability to discriminate speech was reasonably good and increased with increasing amplification, however, increasing clinical experience brought out deviating results

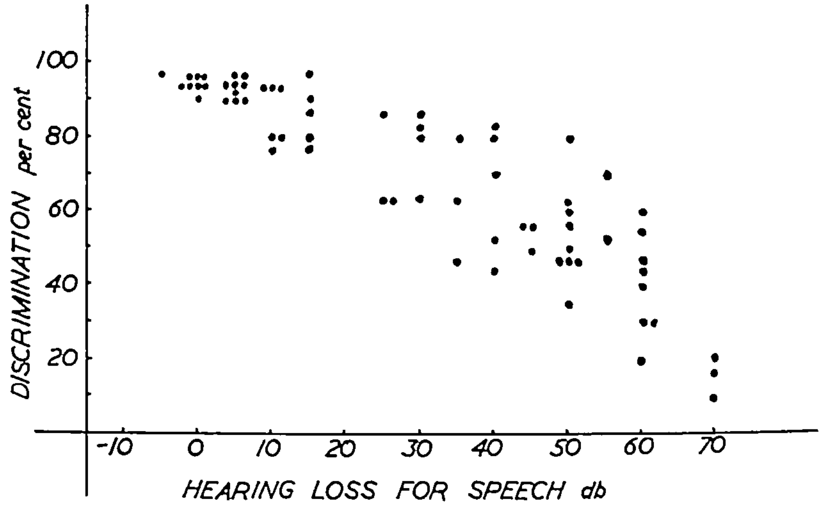

Fig 4 The relation between discrimination ability and hearing loss for speech in 69 cases with complete recruitment tested with the Finnish speech test material[46] Discrimination suffers notably when the threshold loss exceeds 40 db

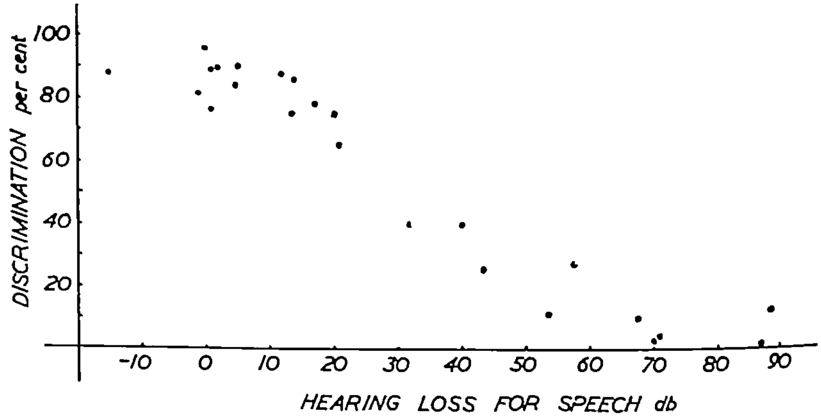

Fig 5 The relation between discrimination ability and hearing loss for speech in 27 cases with complete recruitment tested with the American PB material Discrimination suffers greatly already after 20 db threshold loss Data from Hirsh Palva and Goodman[22]

Poor speech discrimination in acoustic neurinomas has been reported in seven cases by Liden,[47] in two by Schuknecht and Woellner,[48] and in one by Harbert and Sataloff[40] The two cases of our own,[22] to which Walsh and Goodman[50] later added one, also showed very poor articulation function

In quite small threshold losses, discrimination for speech can be disproportionately poor or even nil

The testing experience at our laboratory still suggests that in nonrecruiting neural pathology, excluding acoustic tumors, speech function is lowered but reasonably good It may be that the presence of an acoustic tumor in a nerve reduces the nerve fibers to such an extent that delivery of all complex signals becomes impossible

In conclusion, we do not at present have such audiological tests as would tell us that in one case there is a pure cochlear lesion and in another a pure retrocochlear lesion with 100 per cent certainty We should, therefore, avoid depending too much on audiological tests alone Audiometric tests are an extremely important asset in case evaluation, but it must be remembered that final diagnosis can be made and the lesion located only on the basis of complete anamnestic and clinical data, supported by the results of auditory tests

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Dr. Hirsh Are there any comments on Dr Palva's paper?

Dr. Josef Zwislocki, (Cambridge, Massachusetts) I have comments on the two papers of Dr Palva and Dr Carhart

I am not quite sure when it is safe to say that the difference between bone conduction and air conduction differentiates conductive from perceptive deafness There is one thing which is established beyond a reasonable doubt today, *i e*, that the conduction of sound in the inner ear is essentially the same for air and bone conduction

DR WILLIAM G HARDY, (Baltimore, Maryland) There are gap areas in the diagnosis of hearing losses that need much work For example, we cannot offer much of value to the patient when we find nerve degeneration or an advanced case of otosclerosis There is a toxic condition that leads to nerve degeneration, but we do not know just what it is

In another area is the case of deafness caused by a single blow to the head We hear much about acoustic trauma, and shock pulses causing total deafness, but clinically, we are frequently presented with the case of a man who receives a blow to the head which is not severe enough to knock him down, yet he loses his hearing Or again, he may be knocked down, but not hard enough to cause a fracture of the skull or produce unconsciousness, but still he has a total loss of hearing I think something like this may be the result of a hemorrhage into the labyrinth

In still another area, the inner ear, we see the effects of virus disease Measles and mumps may disturb the hearing, even without an open infection A virus may attack and the lesion may be entirely in the endolymphatic system and begin, for example, in the stria vascularis and the tectorial membrane may roll up We get a greater destruction of the stria on the basal turn, in these cases, and the stria may even disappear at that point

We have many cases of deafness which we cannot explain, some of which are connected with ocular disturbances This may be a toxic involvement through the round window

Then there are the intriguing diseases, such as Ménière's disease, where there is a shift in threshold and the hearing is depressed more in the low tones Why is there only a low tone deafness? In theory this is only possible on the basis of an inner ear conductive loss, but the presence of recruitment makes this not very probable, however, the shift from a high to a normal hearing threshold may take place in only a few hours This again favors the theory of the condition of the hair cells themselves as being important

I have patients who have presbycusis *before* they developed Menière's disease Deafness seems to have been caused by a marked disturbance of the wall of the vestibule

## CLINICAL ASPECTS OF CORTICAL DEAFNESS

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The clinical examination of the peripheral organ of hearing has undergone a radical evolution in the recent decades, thanks to electrophysiological investigation of the cochlea, and to the introduction of the audiometer, however, it has not had its counterpart in a better knowledge of the auditory experience as a whole

More and more attention has been devoted to audiometry, with the result that we know a lot more about hearing but as little as ever about listening Since the assertion of Collet in 1920, that we know nothing about the cortical troubles of hearing, things do not seem to have improved much until 1953, when Aboulker stated that the semeiology of the cortical disorders of hearing is still in its infancy Two years later Alajouanine, in his beautiful book on the functions of the temporal lobe, concluded that it is so far impossible to make an audiometrical diagnosis of a lesion of the auditory cortex

As far as we are dealing with the organ of hearing, physiological, physiopathological and clinical investigation may avail themselves of the same stimuli pure tones, or simple sounds Before these stimuli, the organ of hearing behaves in a well-defined fashion, according to well-known physical and mathematical laws

The appreciation of loudness casts a shadow upon the value of some physical determinations, but that problem, too, has had a satisfactory explanation on a psychophysiological basis As far as tones and simple sounds are concerned, the response in the experimental animal may be compared with the responses which are obtainable in the clinical experiment in man, however, things get more and more complicated as we consider the analysis and the identification of a meaningful message The electrical response of single cortical areas to pure tones, or clicks, provides an excellent basis for the knowledge of the limits, and the excitatory processes, of the auditory cortex, but it does not help in explaining how the cortex may elaborate the psychological aspects of a verbal message

The conditioned thresholds to sounds in the decorticated animal only prove that most acoustically conditioned reflexes take place at some level below the cortex The demonstration afforded by that animal, previously conditioned to different sequences of stimuli, which fails to give differentiated responses after its cortex has been removed, is the only experimental hint to the importance of the cortex in cortical discrimination of auditory patterns Recently, further observations upon this point have been reported The function of the auditory cortex must not be regarded as analytical, on the contrary, it is mainly synthetical The different attributions of sounds must be faithfully transmitted from the ear to the centers in order that they may be correctly recognized, but, when the sound is a meaningful verbal message, it is also necessary that they reach the centers with a certain order in space and time "Reversed" words are not comprehensible, in spite of the fact that they contain exactly the same frequencies and intensities, a poorly known foreign language is not understood if it is spoken rapidly These few facts may serve as an example that there is a wide difference between the recogntion of the physical qualities of a sound and the process of identification of a verbal pattern The former depends upon the working of the auditory apparatus as a whole, the latter is a specific function of the auditory cortex This is a very obvious and widely accepted fact, which should have long since orientated all clinical investigations of hearing at a cortical level

Otologists of many countries have been busy in recent years trying to reveal cortical disturbances of hearing by means of pure tones, which are to be considered as the specific stimulation of the cochlea, cochlear nerve, and the first stations of the auditory pathway The scanty data available in the literature are equal only to the scarce importance of the observations

If we devote some attention to the works of all the great neurologists and psychologists of the last 70 years this seems to be rather surprising In the chapters dedicated to the problem of aphasia, the way to further research in the field of cortical deafness is clearly indicated Until the physiological experiments are able to bridge the gap between form and experience (which is highly improbable) we shall be obliged, when studying sensation at a psychological level, to set apart all the traditional experimental and clinical methods, and to avail ourselves of testing material of a purely psychological value Pure tones and simple sounds must be abandoned, and words or sentences must be resorted to, because they alone own the symbolic, emotive, mnemonic, and evocative qualities which acquire their significance at a cortical level

As a matter of fact, after the failure of tonal audiometry, hearing for the voice has been tested by some authors, in cases of pathology of the temporal lobe, the results did not significantly differ from normal, so that any further possibility of audiometric investigation of the auditory cortex seemed to be precluded At the present state of knowledge there is a sharp passage, in the temporal lobe pathology, from normal hearing to word-deafness, which represents the final stage of most severe lesions We have no means of revealing audiometrically the early or pre-aphasic stages

If we bear in mind the importance of quality, space, time, and rhythm as factors governing the cortical identification of a verbal pattern, we may be easily persuaded that modern electroacoustic engineering gives us a chance of altering one or more of these factors in a way which can be exactly defined and easily repeated, an entirely new testing material may be put at our disposal, for the detection of early troubles of cortical hearing, in the same way as the audiometer reveals early and unsuspected troubles of the frequency and intensity function It is not difficult to explain why, in limited lesions of the temporal lobe, evident disorders of verbal hearing are rare events

The nervous sensory apparatus works according to a principle of redundancy, which is very common to all natural organizations As a consequence, even if a fairly large number of its structures are put out of function, sufficient contacts are always possible between the centers and the external world

On the other hand, speech also, as a means of communication, works along the same principle Every speech sound contains an enormous amount of information units, far outnumbering the minimum that is theoretically required for its differentiation from another sound, as a consequence, even if a certain number of those units get lost, due to faulty transmission or reception, the speech sound is still recognizable, moreover, if one considers the rather rigid way in which speech sounds are combined into a word, or words into a sentence, a very considerable loss of quality is necessary to make speech no longer intelligible It appears logical to suppose that the conditions for the identification of a verbal message grow more difficult if the poor quality of the message is associated with a poor working of the neural sensory structures, in other words, when a peripheral distortion is associated to what we may call a central distortion The distortion may affect intensity, frequency, and time Any alteration of these factors will alter the value of the equation

$$I \text{ (amount of information)} = 2\,t\,w \log \frac{S+N}{N}$$

(Where $t$ is the duration of the signal, $w$ is the width of the usable frequency range $S$ the maximum amplitude of the signal, $N$ the minimum discernible difference of intensity)

thereby reducing or increasing the amount of information

Other factors such as space and rhythm must also be taken into consideration, therefore, we developed a series of clinical audiometric investigations whose logical basis was that of sensibilizing the traditional speech tests by making them more difficult in several ways (cutting of frequencies, acceleration, periodic interruption, increase of the length of the message, alteration of meaning, rhythm, accentuation) Some of these tests have already been performed in an extensive number of cases of tumors of the temporal lobe, and of degenerative changes of the cerebral cortex, due to old age In all these cases traditional tonal and speech audiometry failed to reveal any significant deviation from normal Some other tests have been so far experimented with in a more limited number of cases, mainly or exclusively old-aged subjects

FACTORS AFFECTING THE CORTICAL RECOGNITION OF THE VERBAL IMAGES

| Factors | Related Tests |
|---|---|
| Physical Qualities of the Verbal Pattern | Distorted Voice,<br>Interrupted Voice |
| Duration of the Signal | Accelerated Voice |
| Length of the Message | Long Sentences or Lists of Words |
| Meaning | Meaningless Sentences "Reversed" Sentences (Ex the cat is on the table table the on is cat the) |
| Rhythm | Prosodic Alteration (Accent Shift)<br>Aperiodic Variations of Speed,<br>Reversed Sentences |

Fig 1

*1* Distorted voice Lists of PB disyllabic words have been presented monaurally at 50 db above threshold, through a low-pass filter capable of reducing discrimination to 70 to 80 per cent in the normal subject Temporal lobe tumors present an average discrimination which is poorer in the ear contralateral to the tumor (50 per cent vs 65 to 75 per cent in the ipsilateral ear )

*2* Interrupted voice A discrimination of 80 per cent of PB disyllabic lists is the rule in the normal subject, if the voice at 50 db above threshold is interrupted periodically 10 times per second, the ratio voice silence being 1 1 Tumors of the temporal lobe show worse discrimination in the ear contralateral to the lesion (30 to 40 per cent less as an average)

*3* Accelerated voice If the number of words per minute of the speech is increased from the normal (about 150 words per minute) to about 350 words per minute, the discrimination always approaches 100 per cent in the normal subject, however, the threshold is raised by 10 to 15 db Tumors of the temporal lobe may present a normal threshold shift, but the discrimination never attains 100 per cent in the contralateral ear

4 Long messages When listening at a comfortable level, a normal subject is able to repeat 100 per cent of obvious

AGED PERSONS

| Test | | Response |
|---|---|---|
| Distorted Voice | + | Fairly Good |
| Interrupted Voice | +++ | Very Poor in Both Ears |
| Accelerated Voice | +++ | |
| Long Sentences or | +++ | Very Poor in Both Ears |
| Long Lists of Words | ++ | |
| Meaningless Sentences | + | Fairly Good |
| Reversed Sentences | +++ | Extremely Poor |
| Prosodic Alteration | +++ | Extremely Poor |
| Velocity Fluctuations | ++ | Poor |

TEMPORAL LOBE TUMORS

| Test | | Response |
|---|---|---|
| Distorted Voice | +++ | Poor in Contralateral Ear |
| Interrupted Voice | + | |
| Accelerated Voice | ++ | |
| Long Sentences or | +++ | Poor in Both Ears<br>Only in Left Side Lesions<br>(Right handed Pts ) |
| Long Lists of Words | ++ | |

(+ indicates validity of the test.)

Fig 2

sentences of ten words, and respectively 70 per cent of 15 words and 40 per cent of 20 words Tumors of the temporal lobe show a very poor performance (respectively 70-10-0 per cent for monaural left and right, or binaural audition, when the tumor is located in the left hemisphere in right-handed patients No deviation from normal is observed in right-sided tumors

The results obtained appear to be specifically indicative of an impairment of the auditory cortex, as no similar responses have been observed in the many cases where the tumor was located outside the temporal lobe

It is interesting to note that, as far at least as the integration of a distorted message is concerned, there seems to be no real dominance of one hemisphere over the other The poorer response is always in the contralateral ear, regardless of the side where the lesion is located, however, for the function of memory, the left hemisphere in right-handed patients is clearly dominant Cases of severely increased intracranial pressure often give bilaterally poor responses

The observations made in tumoral pathology prompted us to investigate the response to the same tests in old-age subjects, showing the best possible audiometric curves in relation to age and the best possible performance in psychometric tests, and normal responses to traditional speech audiometry The results have been even more demonstrative than those observed in the group of temporal lobe tumors, of course, no difference existed in monaural tests between the response of the two ears The only exception was observed in the test of distorted voice Discrimination was better in aged subjects than in temporal lobe tumors This may be tentatively explained by the fact, that due to the progressive loss over high frequencies, the aged persons have been slowly getting accustomed to the cortical integration of messages lacking the higher portion of their acoustic spectrums

The interrupted voice test gave much poorer responses than in tumor cases The same happened with the accelerated voice test, the long sentences test gave as poor results Some of the poorer responses may depend upon the greater synaptic delay in the cortex In other cases, they may be due to the lack of partial compensation by the contralateral temporal lobe The comparative evaluation of the results of our tests in the old age and tumor group of cases is an implicit confirmation that the auditory troubles of old age are mainly cortical in origin, and that insofar as the process of cortical elaboration of the message is concerned, it does not matter whether the cortical lesions are brought about by compression and invasion, or by primary atrophic and degenerative changes

This fact has persuaded us in recent months to extend further our psychoacoustic researches in the aged subjects, who form a far more numerous and homogeneous group than tumor cases, with the conviction that the results may be a proof of the validity of new testing material, and an indication of its possible employment in the study of cortical pathology from other causes

The new testing material used consists of

*1* Meaningless sentences  The importance of meaning does not much affect the correct repetition of sentences, with results only 20 per cent less as compared with the control group

*2* Alteration of rhythm  The importance of rhythm seems to be of paramount importance in the correct recognition and repetition of sentences  Rhythm may be altered by, *1* irregularly varying the output velocity of the speech, or *2* shifting the accent of words to wrong places

In the old-age group, when compared with the control group, the percent of correct responses falls respectively from 100 to 70 per cent, and from 50 to 0 per cent

These investigations further helped us to establish which functions of the auditory cortex and associated areas are more liable to be compromised, and which tests are more suitable for the detection of a cortical impairment of hearing, whose clinical evidence is a very late and very rare occurence  Modern electroacoustic facilities allow us to multiply these tests, and to perform them under conditions of so far unknown reliability  A first step seems to have been made in the creation of a new semeiology of the cortical disturbances of hearing

This new semeiology is not only diagnostically important, but it entails interesting physiological and psychological implications, *viz* the relative importance of crossed and uncrossed fibers along the auditory pathway, and the dominance of one hemisphere over the other, moreover it leads to a considerable widening of the term of "deafness' as it is generally accepted today, especially in old age, and offers the hope of a better solution of some of the many problems regarding prothesic adaptation and the re-education of the deaf

DR HIRSH Are there any questions or comments on Dr Bocca's paper? Dr De Sá has a comment

## AUDIOLOGIC FINDINGS IN CENTRAL NERVE DEAFNESS

GERALDO DE SA,

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The detection of nerve deafness of central origin, is the latest trend in audiology The development of electric audiometry, and mainly of speech tests, brought a greater interest of the audiologist and the otologist in general to the possibility of the existence of a complex pathology, under the uncertain diagnostic of nerve deafness For the past five years literature has been abundant on the subject of deafness caused by tumors and traumatism, therefore, greater interest arose with the better knowledge of the possibilities of speech testing Attention is being called to the importance of speech discrimination losses for the detection of central nerve deafness since 1953 by Theo E Walsh Also, a better study of the recruitment phenomenon permitted the audiologist to separate cases of cochlear and post-cochlear nerve deafness

Perceptive aphasia was studied for a long time by the neurologist, and only recently was developed in the field of the otologist It seems to us that the two portions of the acoustic nerve, terminal organ, and acoustic pathway and brain projections, should be studied separately, being considered the cochlea as a sound selector and the pre-cortical and cortical areas as the final analyzers The audiometry with pure sounds would be, evidently, of great importance for the diagnosis of diseases of the selective organ, the organ of Corti, however, the identification of the composed sounds, and more especially of the speech sounds, being accomplished on the pre-cortical or cortical centers, would be better made with the help of testing measures that demand more intensive cerebral implication.

This seems to be today, a generalized idea for the audiologists. To test the perception of a word, no better testing material could be available than the word itself. For all of us dedicated to the speech audiometry the importance of the discrimination tests for diagnosis soon become apparent. Besides, the use of phonetically balanced word lists holding identical percentage of sounds of a language, would permit testing a patient unable to hear this language well, with material adequate for his disability.

In our country, where otosclerosis affects only 15 per cent of the cases of deafness, the most common symptom brought by a patient to the otologist is to hear, but not to understand. It seems to be that nerve deafness is our real toll. As a matter of fact in nearly 600 cases of deafness studied in the last four years, we found about 40 per cent of cases of so-called "nerve deafness." Under these local circumstances the discrimination tests became of great importance to us.

We used on our patients, for determination of discrimination score, phonetically balanced lists, prepared by ourselves at Central Institute for the Deaf, St. Louis, Mo., in June, 1952. Since the beginning of the work with the phonetically balanced word lists, in September, 1952, we decided to observe a specific approach, by registering each answer of the patient, and not only establishing a curve. In this way we believed we could, after enough experience, see which sounds were most commonly lost by the patient in the several diagnostic groups.

Employing phonetically balanced lists, containing all the sounds of the language in identical percentage, it was easy to disintegrate each monosyllable lost, in its phonetical components, and to establish definite medias referring to all the phonems of the language. This study is presented today, and might lead to interesting conclusions. On the other hand a careful control of the improvement of hearing and discrimination after therapeutical measures could be established.

Based on our observations, we agreed with Dr. Walsh that the cases of otosclerosis showed very little discrimination loss, while the nerve deafness showed a greater one, and that a certain type of deafness showed an extremely great discrimination loss In cases of nerve deafness, some showed recruitment and some did not Those with recruitment, we named cochlear deafness, and on our charts are represented by five cases of hydropsy, three cases of toxic neuritis, and two cases of acoustic trauma

Among the cases with no recruitment, that we named retro-cochlear deafness, we charted two cases of skull trauma, two cases of epilepsy with focus on the left temporal lobe according to electroencephalography findings, one case of multiple sclerosis, one case of general toxicosis, two cases of supposed cortical deafness, and two cases of presbycusis of the Schuknecht physiological type

Among the cases of otosclerosis, ten patients with no signs of nerve involvement were chosen Their media of pure tone loss was 65 db, and their media of discrimination was 84 per cent Among the 48 phonems in the Portuguese language, 15 were heard by all the patients, 1160 phonems were given to the ten patients, and only 83 were lost, giving a media of 7 15 per cent of discrimination loss Among the phonems lost the F's came with the highest percentage, 40 per cent, followed by the S's with 35 5 per cent The D's, the B's and the AN's followed with a smaller percentage, and among the rest, the losses were very small

The cases of recruiting nerve-deafness showed a very different aspect Their media of pure tone loss was 40 dbs, and their discrimination was 70 per cent Five cases had pure tone around 20 to 25 c p s Among the 48 phonems in the Portuguese language (as spoken in Brazil) 11 were heard by all the patients From the given 1160 phonems 145 were lost, giving a media of 12 5 per cent of discrimination loss The F's were the phonems lost more often, 70 per cent, and the S's gave a percentage of loss of 63 328 per cent, the IN's and the B's followed with 40 per cent and of the diphthong AI 50 per cent was lost Of the D's 30 per cent were lost, and the Z's, UN's, V's and T's followed The rest of the phonems were in a smaller percentage It was evident that cases of nerve deafness with recruitment, lose more consonants,

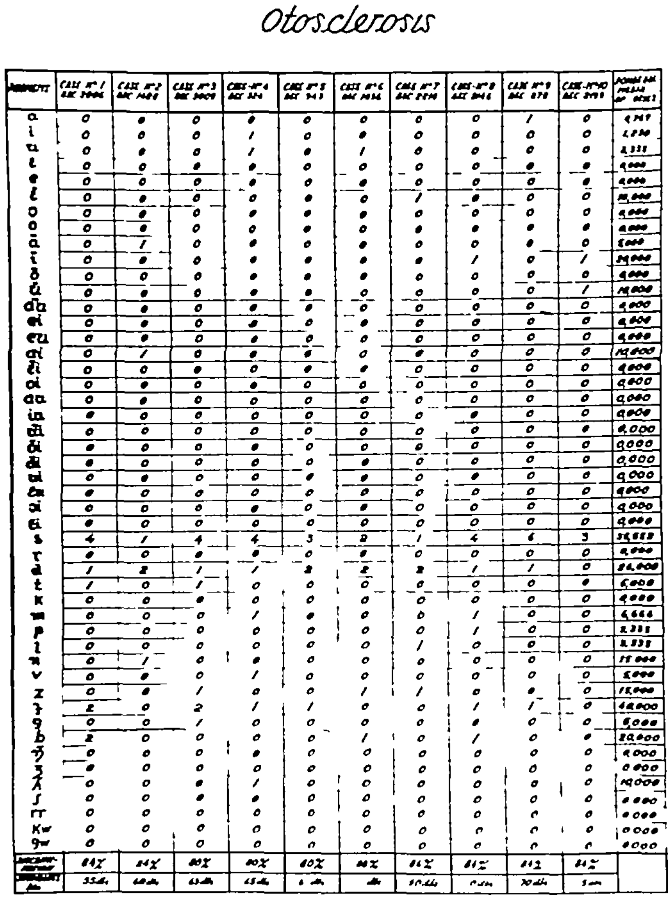

Otosclerosis

Fig 1

among them, F's, the S's, the D's, the T's and the B's One could detect the diagnosis by the almost complete losses in S's, that were scarcely heard at all Those cases showed also sloping curves towards the high frequency tones from 2000 c p s up Their bone conduction was poor, but present

Now we come to the cases that are mainly the reason for this communication—the nerve deafness cases without recruitment, that we charted as retro-cochlear deafness Their media of pure-tone loss was 45 dbs , and one case had no pure tone loss at all Their media of discrimination was 45 per cent Among the 48 phonems in the Portuguese language,

Cochlear Deafness
(Recruitment)

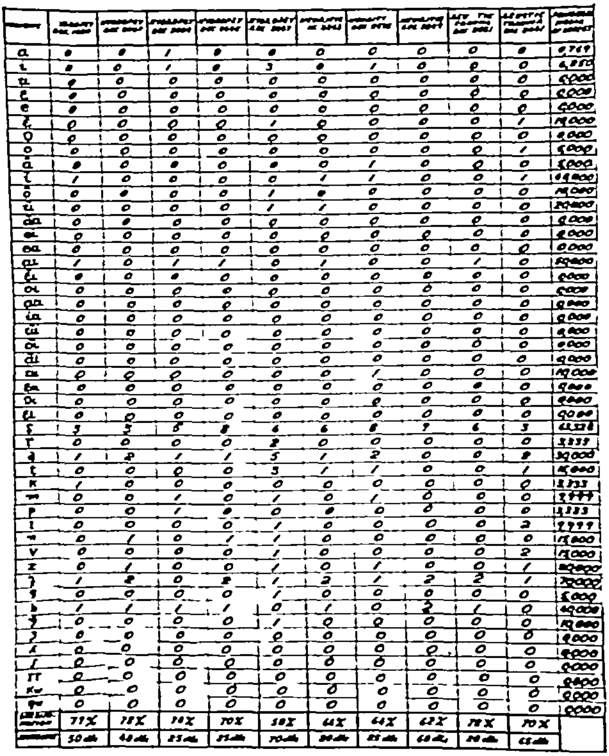
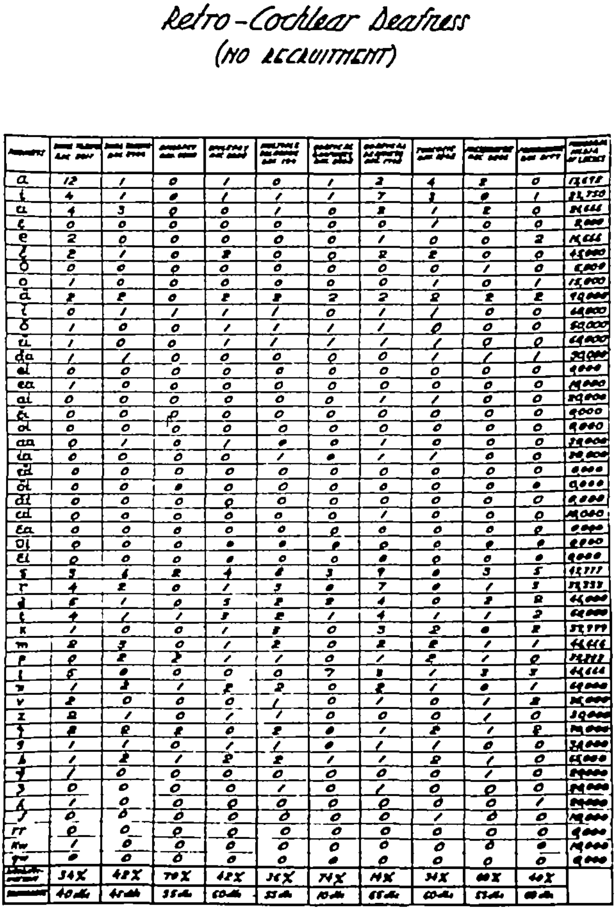


Fig 2

none escaped being lost by some patients From the given 1160 phonems, 347 were not heard, which gives a media of 29 913 per cent of discrimination loss

On the selection of the phonems lost, we saw a complete change from the other types of deafness The AN's, that until now showed practically no losses, showed 90 per cent loss The F's presented 70 per cent of losses, the IN's and the UN's showed 60 per cent, and so did NN, also a nasal sound The B's showed 65 per cent loss, and again the nasal sounds ON and the nasal diphthong AO showed 50 per cent



Retro-Cochlear Deafness
(No recruitment)

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| a | 12 | 1 | 0 | 1 | 0 | 1 | 2 | 4 | 2 | 0 | 13,678 |
| i | 4 | 1 | 0 | 1 | 1 | 1 | 7 | 3 | 0 | 1 | 22,750 |
| a | 4 | 3 | 0 | 0 | 1 | 0 | 2 | 1 | 2 | 0 | 16,666 |
| e | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 8,000 |
| e | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 16,666 |
| i | 2 | 1 | 0 | 2 | 0 | 0 | 2 | 2 | 0 | 0 | 45,000 |
| ô | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 5,000 |
| o | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15,000 |
| ã | 2 | 2 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 90,000 |
| ĩ | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 60,000 |
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| ũ | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 60,000 |
| da | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 30,000 |
| ei | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9,000 |
| ea | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18,000 |
| ai | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 29,000 |
| ẽi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9,000 |
| oi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9,000 |
| au | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 19,000 |
| iu | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 30,000 |
| ẽi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8,000 |
| õi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9,000 |
| ãi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8,000 |
| ei | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 18,000 |
| ea | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8,000 |
| oi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8,000 |
| ei | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9,000 |
| s | 3 | 4 | 2 | 4 | 8 | 3 | 9 | 0 | 3 | 5 | 42,777 |
| r | 4 | 2 | 0 | 1 | 3 | 0 | 7 | 0 | 1 | 3 | 32,333 |
| d | 6 | 1 | 0 | 5 | 2 | 2 | 4 | 0 | 2 | 2 | 46,000 |
| t | 4 | 1 | 1 | 3 | 2 | 1 | 4 | 1 | 1 | 2 | 60,000 |
| k | 1 | 0 | 0 | 1 | 3 | 0 | 3 | 2 | 0 | 2 | 33,999 |
| m | 2 | 3 | 0 | 1 | 2 | 0 | 2 | 2 | 1 | 1 | 46,666 |
| p | 0 | 2 | 2 | 1 | 1 | 0 | 1 | 2 | 1 | 0 | 32,222 |
| l | 5 | 0 | 0 | 0 | 0 | 7 | 8 | 1 | 3 | 3 | 46,666 |
| n | 1 | 2 | 1 | 2 | 2 | 0 | 2 | 1 | 0 | 1 | 60,000 |
| v | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 2 | 26,000 |
| z | 2 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 39,000 |
| f | 2 | 2 | 2 | 0 | 2 | 0 | 1 | 2 | 1 | 2 | 28,000 |
| g | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 34,000 |
| b | 1 | 2 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | 0 | 45,000 |
| j | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | [illegible] |
| ʒ | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | [illegible] |
| ʎ | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | [illegible] |
| ʃ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | [illegible] |
| rr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9,000 |
| kw | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18,000 |
| gw | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9,000 |
| [illegible] | 34% | 48% | 70% | 42% | 36% | 74% | 44% | 34% | 60% | 40% | |
| [illegible] | 40 db | 45 db | 35 db | 60 db | 55 db | 10 db | 65 db | 60 db | 55 db | 60 db | |

Fig 3

loss, while another nasal phonem, the EN, showed 45 per cent The T's lost 50 per cent, and the B's 65 per cent, the S's 47 per cent, the M's 46 per cent, and the L, an easy phonem in Portuguese, 46 per cent loss The K's, V's, Z's and G's all showed losses up to 30 per cent

It was interesting to observe the discrimination of phonems lost by other types of patients, and the appearance of fantastic answers, difficult to find in other types In the ten patients, more than 50 fantastic answers were given, which raises the percentage to more than 10 per cent Although showing heavy loss, the S's were relatively well heard compared with other types of deafness Mistakes among consonants were very common The most frequent were F for S and T, T for D and D for T, P for T, and D and F for S Among the cases, we have charted two skull traumas without any other disablement than dizziness and deafness Case No 2986 does not respond to any caloric excitement in either ear, the two cases of epilepsy showed abnormal encephalogram with focus of slow activity in the left temporal area with sharp and spiky waves on the left anterior temporal zone Case No 2892 showed, in the Cawthorne-Hallpike test, directional preponderance for the left Examined thoroughly by the neurologist, Dr M C Barros, no other nervous symptom was found It would be interesting to note that another patient with focal epilepsy on the right side showed no loss of discrimination worthwhile, pure-tone media around 40 dbs and discrimination score 90 per cent

One case of multiple sclerosis had a linear, flat curve around 55 dbs, no bone conduction, and a very poor discrimination It has been followed now for six years and hears nothing at all for the last two years Regarding the general toxicosis, one patient has for a long time taken alcoholic drinks to excess and has a great difference between the left and right ears with very bad discrimination in both Hearing in one ear is today almost lost, and the other almost as bad, as he continues the same habit

Other cases of supposed cortical deafness refer to a patient with almost normal pure-tone level, and great discrimination loss, and another with great loss of discrimination and pure tones, that recurred with clinical treatment to a 90 per cent discrimination score, this patient being long underfed because of religious motives The two cases of presbycusis showed no recruitment and no history of toxidity and could be put in the class of general senile breakdown

We could not find in any examination signals that could be referred to lesions on the pathway between the cochlea and the cortex, but we are convinced that patients with flat pure tone threshold, great discrimination loss, mainly of nasal sounds, many consonant mistakes, frequent senseless answers, no recruitment, bone conduction very low or absent, have retro-cochlear deafness and if all these signals are backed by the existence of directional preponderance or electroencephalographic findings, cortical deafness could be suspected

## SUMMARY

The author presents several cases of central deafness, some of them confirmed electro-encephalographically, and studies their audiological findings

*a* Tono-audiograms are presented for each case, emphasis being placed on the linear aspect of the curves

*b* Portuguese speech tests performed, showed some errors that became characteristic, therefore the author states the need of speech tests (logo-audiometry) being made specifically, and not only numerically, *i e*, each word must be registered by the examiner as repeated by the patient, so as to permit further observation of the results obtained with treatment, as well as to identify certain hearing losses The following observations were made

First, Nasal sounds are normally lost in central deafness (An, En, In, On, Un)

Second, The S's are well perceived while they are the first to be lost in the cases of cochlear deafness

Third, There is great recurrence of mistakes of certain consonants as T for D, D for T, F for P, P for T, (percentual is given)

Fourth, Frequently fantastic answers are obtained

*c* As a clinical aid to the diagnostic, the Cawthorne-Hallpike test will show directional preponderance in some cortical deafnesses

*d* The author fails to find a differential diagnosis in the cases of deafness by envolvement of structures between the cochlea and the cortex, but assumes that patients with linear tono-audiograms, no recruitment, no directional preponderance and negative encephalographic chart, will in most cases have lesions in the tuberculum quadrigeminus inferior or in

the medical geniculate body or in the nuclei of the acoustic pathway

**DR. HIRSH** Thank you, Dr Sá Any other questions or comments?

**UNIDENTIFIED DOCTOR** Excuse my very bad English, but I was impressed by what Dr Sá said, because we made the same investigation, and in Spanish words, to have in the corresponding language different quality deep tones

**DR GREINER** When you have a very strong amplification your distortion becomes greater than when you have a middle amplification When you have a peripheral or cochlear distortion this remains the same on every level of intensity When you have a cortical lesion your distortion first diminishes and then, when the distortion goes up, you have a greater discrimination

**DR. HIRSH** Tomorrow you will hear the physiologists tell us about the cortex, and how they will interpret some of the clinical results of today

# PENDULUMS, TRAVELING WAVES, AND THE COCHLEA

## Introduction and Script for a Motion Picture*

G V BÉKÉSY,
Harvard University,
Cambridge, Massachusetts

## I INTRODUCTION

The purpose of this film is to make us familiar with the properties of traveling waves which seem to play a role in hearing Only transverse waves are described, since the movements of the basilar membrane seem to be of this sort The vibration amplitudes on the human basilar membrane, during stimulation with even a very strong sound, are so small that it would be very difficult and expensive to photograph them For this reason the traveling waves are demonstrated on models These models have the great advantage that they permit us to investigate several different phenomena as a function of a number of variables

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*This film originally scheduled as a portion of the session on the Physiology of Hearing was shown Tuesday evening May 14 in the clinics and laboratories of the Central Institute for the Deaf, St. Louis Missouri.

In the beginning of the film it is demonstrated that, even with an oscillating system made up of only two coupled pendulums, the energy of one pendulum does not stay attached to the pendulum in motion, but through coupling, is transmitted to the second pendulum Naturally, if there are several pendulums coupled together, the energy flows through one pendulum to its neighbor, and in this way a traveling wave is formed In general, the same holds for membranes or for any system of this type

Propagation, reflection and standing waves are illustrated, and it is demonstrated that even with a set of coupled resonators, such as those described in the resonance theory of Helmholtz, transients always produce traveling waves

The film closes with an enlarged model of the cochlea On the model the nerve supply is represented by the sensory nerves of the human skin It is the skin which picks up the traveling waves along a plastic membrane The vibrations felt are similar to those on the basilar membrane of the human ear, and they produce a sensation which is very sharply localized along the membrane even though the maximum of the vibration amplitude distribution is quite flat Changing the stimulating frequency makes the sensation move up and down on the skin of the arm, thus permitting frequency analysis by place determination

## II SCRIPT

This film illustrates the principles basic to the complicated vibration pattern of the inner ear

Part I shows the production, propagation, and reflection of waves in a system of coupled pendulums

Part II shows traveling waves similar to those observed in the inner ear

Part III shows an enlarged dimensional model of the vibrating parts of the cochlea

*Part I—System of Coupled Pendulums*

The pendulum system consists of a series of green balls *B*, each suspended from the supporting rod *A* by a thread (see Fig 1) Adjacent pendulums are coupled by small orange balls attached between them When the large driving pendulum is coupled to the supporting rod, it sets the whole series in motion simultaneously, when it is coupled to the series only (by an orange ball) it sets the first pendulum in motion

In a system of two coupled pendulums, when one is set in motion it transfers its energy to the other, which in turn returns the energy to the first

As the coupling is increased, by lowering the coupler, the amplitudes of the coupler become larger, and the energy transmission is, therefore, increased

When there are four pendulums, the energy travels a greater distance from the point of origin

In a long series of pendulums the coupling transports energy away from the source and forms a traveling wave

*The formation of traveling waves under special conditions*

In the inner ear the driving forces act on large sections of the vibrating system This distribution of forces can be simulated in the pendulum system by setting the driving rod in oscillation When all the pendulums are of the same length and all are driven simultaneously, they swing in phase and no waves are produced The height of the coupling balls is immaterial

If the driving forces act on only half of the pendulum series, traveling waves develop in the center and spread in both directions When the distribution of forces is constant, a discontinuity in the lengths of the pendulums will also cause waves to spread in both directions from the discontinuity, however, when the driving frequency is lower than the resonant frequency of the pendulums, no waves are

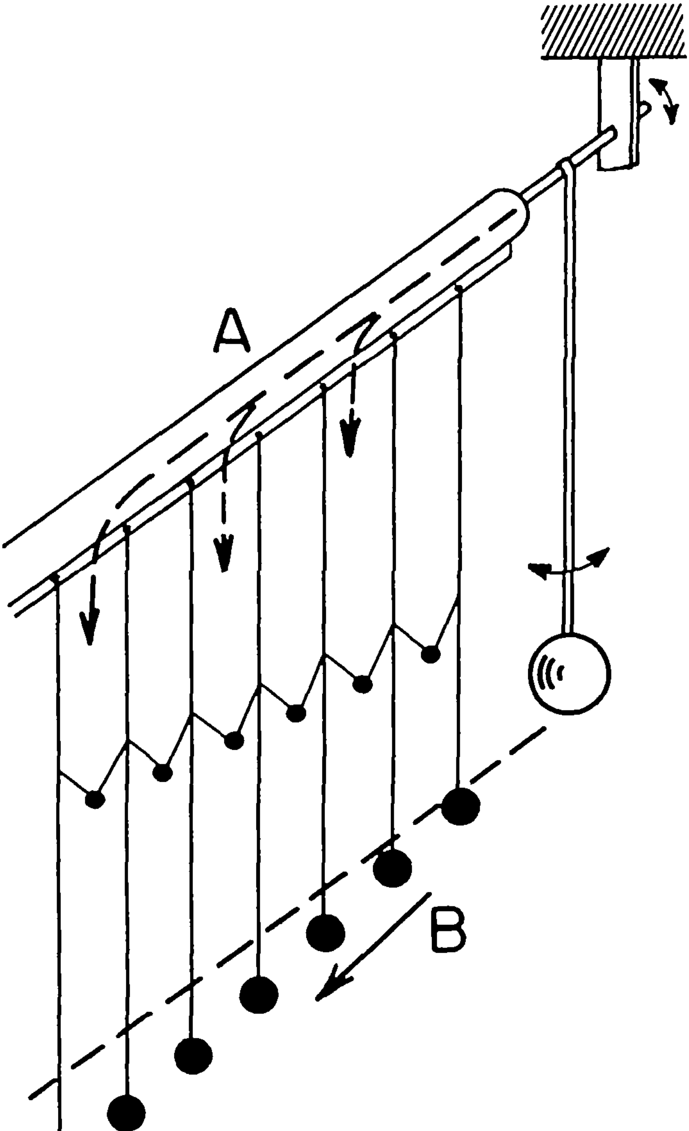

Fig 1

formed, even though the force acts on only one end of the series

*Propagation of Waves*

When an oscillation is suddenly transmitted to one end of the coupled pendulum series, traveling waves of varying speed are produced The high frequency components of the transients produce short waves, and these waves travel faster than the long waves This is called dispersion In a dispersive system, two types of velocity can be seen, phase velocity and group velocity

Phase Velocity—the maximum of the small sinusoidal waves moves quickly from right to left and disappears at the front edge of the group (see Fig 2)

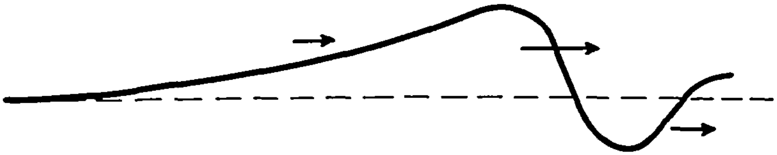

Fig 2

Group Velocity—the whole group of sinusoidal waves moves into the region of the undisturbed pendulums at a much lower velocity With smaller coupling the difference between group and phase velocity is even more pronounced

When the oscillation is continuous, however, only the phase velocity can be observed In order for us to see group velocity, transients are necessary The wave length for a given frequency depends upon the amount of coupling When the coupling is large, the waves are long When the coupling is small (the orange balls high) the wave length is small

*Reflection*

Whenever a traveling wave reaches a discontinuity, total or partial reflection occurs and standing waves may appear Standing waves are characterized by nodes and loops in fixed positions  Usually the movements of adjacent loops are out of phase (see Fig 3)

In the picture an electro-magnet holds one of the central pendulums in a fixed position, and standing waves occur between the stationary pendulum and the driving source The moment the pendulum is released traveling waves occur and move along the whole system  A local discontinuity in a traveling wave produces standing waves as a consequence of reflection

### *Part II—Two systems illustrating traveling waves similar to those observed in the inner ear*

A system of pendulums can simulate the vibration pattern observed in the cochlea of a living guinea pig or in a prepara-tion of human temporal bone  When the lengths of the pendulums decrease continuously from one end to the other, what we observe is traveling waves moving in the direction of the longer pendulums  For the past 100 years Helmholtz's theory has dominated the field of hearing

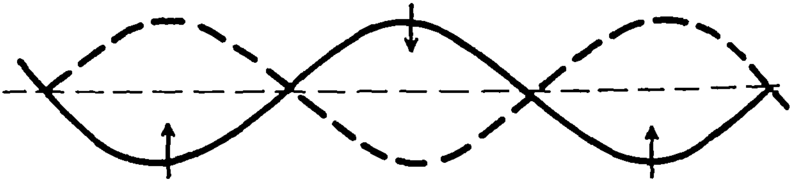

Fig 3

### *Helmholtz Theory*

Lord Kelvin photographed Helmholtz in his laboratory in 1894—the age of kerosene, gaslight, and basic research  According to the resonance theory, there are free resonators in the inner ear, each of which resonates at a different frequency  Without coupling, the pendulum series becomes a system of free resonators  The short pendulums at the far end are fast moving, the long ones at the front are slow moving

Traditionally, it has been assumed that traveling waves do not occur in a system of free resonators, but when the whole support of the pendulums is set in oscillation at a high frequency, a traveling wave develops at the onset of the oscillation Its maximum amplitude is in the region of the shorter pendulums As the driving frequency is lowered the maximum moves toward the longer pendulums

Transients are important in the recognition of speech and music For transients there is almost no difference between the resonance and traveling wave theories of hearing

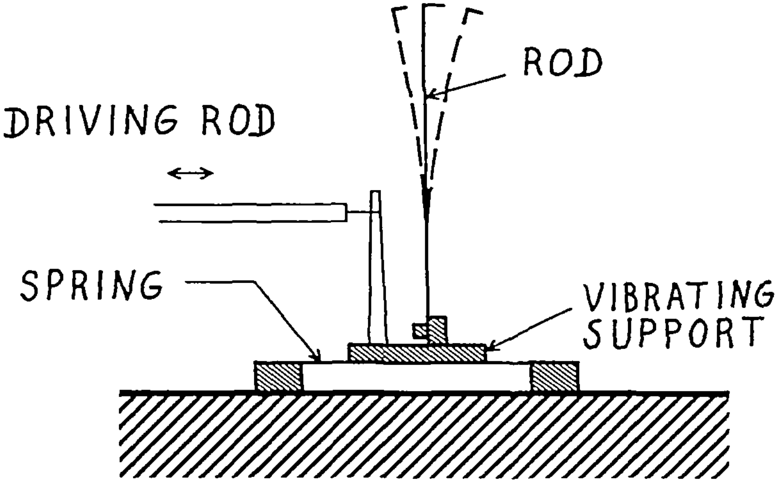

Fig 4

*Reed System*

In the following pictures, the same phenomena are illustrated with a series of reeds attached to a supporting base which can be set in vibration by a driving rod The reeds are tuned at equal intervals and their resonant frequencies are within the range of hearing The reeds in front are stiff and resonate at higher frequencies, those in back at lower frequencies (see Fig 4)

Applying a sinusoidal vibration to the support sets the reeds in motion Reeds that resonate at frequencies close to the driving frequency vibrate at the largest amplitudes As the driving frequency is lowered, the region of maximum vibration shifts toward the low-frequency reeds

The reeds shown vibrate 60 times per second, and only a blur could be seen, but when the pictures are projected 100 times slower, the movements of each reed can be followed The white line made by the tips of the reeds describes a vibration pattern characteristic of free resonators

The reeds below the resonance point—the point of maximum vibration—are vibrating 180 degrees out of phase with the reeds above the resonance point (see Fig 5)

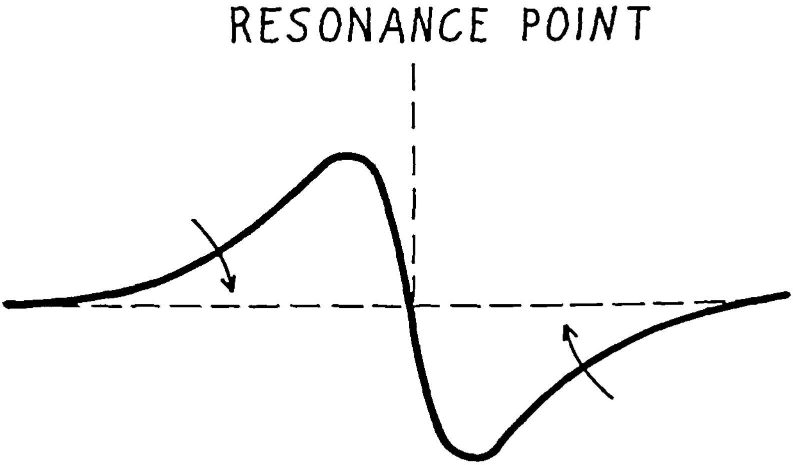

Fig 5

In spite of the assumption that traveling waves do not occur in a system of free resonators, they can be seen forming during the onset and termination of a periodic driving force The resonance theory of hearing assumes the vibration pattern you have just seen, that is, resonating elements vibrating freely

In the basilar membrane, however, each element is coupled to its neighbor This coupling is simulated here by inserting a rubber band along the reeds With the reeds thus coupled, displacement of one reed moves its neighbor

Because the driving rod is atached to the supporting base, all the reeds are exposed to the same driving force As in the coupled pendulum series, traveling waves are present, even for continuous vibrations In order to avoid reflections, damping has been added in the form of a piece of sponge rubber At normal speed we would see only the amplitudes of the vibrations moving along the row of reeds

The traveling waves are similar to the waves produced in the cochlea of an anesthetized guinea pig or in a preparation of the human cochlea, but in the cochlea there is better damping

In an elastically coupled reed system, a traveling wave does not lose energy as it travels When the wave strikes an obstacle, such as the end of the reed system, it is reflected, and standing waves result The same phenomenon is shown at normal speed and in slow motion The adjoining parts of the basilar membrane are coupled in part by the fluid surrounding the membrane

If we remove the rubber band from the reed system and immerse the reeds partially in water, the resulting frictional coupling produces traveling waves similar to those produced with elastic coupling The next picture shows the combined effects of both types of coupling As the frequency is lowered continuously, the point of maximum amplitude moves in the direction of the low-frequency reeds

*Paradoxical Waves*

The lower part of the next picture shows the wiring diagram of a low-pass filter, the upper part represents the voltage across each section The waves move from left to right, but with a high-pass filter the waves move from right to left, that is, toward the source of the energy Waves traveling *toward* the source are common in electrical networks but are rarely seen in nature Experiments show that they can occur in the cochlea

We can duplicate these paradoxical waves in the reed system by exerting a driving force on a whole section of damped reeds simultaneously When this is done, the driving force can be moved a certain distance along the reeds without changing the *direction* of the waves

*Part III—A model of the cochlea with nerve supply*

It is hard to imagine how traveling waves act on the sensory nervous system Our best approach is through an experiment With dimensional analysis we can make models of ships and airplanes that simulate all the phenomena of full-scale vessels In the same way we can contruct an *enlarged model* of the cochlear duct that incorporates the mechanical data of the human cochlea Several such models have been constructed, of which the most recent is in Gottingen

The model used here consists of a plastic tube with a membrane that is thicker at one end than at the other The tube is filled with water and at the thick end contains a vibrating piston corresponding to the stapes footplate

Sinusoidal vibrations produce traveling waves on the membrane The maximum of the vibration is close to the piston (stapes) for higher frequencies

When the forearm is placed on the vibrating membrane, even though the maximum is broad, the sensation is concentrated in a small region of the skin As the frequency changes the locus of the sensation moves along the arm

The subject moves a pointer along his arm to show the locus of the sensation for a given frequency The sensation extends over only 2 or 3 cm , as is shown by the small oscillating movements

Preparations of the cochlea show that there is in the inner ear a vibration pattern with a broad maximum whose locus changes with frequency, and experiments indicate that the nervous system sharpens this maximum

At the low frequencies the nervous system can perform a frequency analysis by responding directly to the frequency of the vibration, but at the middle and higher frequencies only the locus of the maximum determines the pitch

The impressive factor of this neuro-mechanical model is that it can perform a frequency analysis much more quickly than can any known electrical filter system

The locus of the sensation on the skin is determined with equal accuracy whether the frequency is presented for a second, or for as little as 2 cycles—which in this experiment is 0 02 second

For all our technical skill when nerves are involved, nature is far ahead of us

### *Acknowledgment*

The electronic equipment used in these experiments and the shooting of the film were achieved with the collaboration of Rufus L Grason

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Background information concerning the patterns of traveling waves in the cochlea and on the conditions of appearance of traveling waves will be found in the following articles

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The impressive factor of this neuro-mechanical model is curious, the better off is the clinician, and there is no other area of auditory function that has so clearly shown this picture of basic knowledge contributing to successful clinical procedures than studies of the sound conduction process of the middle ear

We see the successful beginning of middle-ear surgery back in 1890[6] with attempts at mobilizing ankylosed stapedes Through many variations this procedure was replaced by the fenestration operation, first tried in one form or another around 1900,[7] and finally perfected to a single stage, and highly successful method, by Lempert some 15 years later [5] Actually it was the success of this operation that inspired some concentrated research on the conductive processes of the ear, and as a result of the subsequent understanding of the middle-ear mechanics there has been developed a number of operative procedures for the reconstruction of chronic middle-ear conditions that up to now caused deafness that had to be lived with

Our purpose here is to consider the way sound is transmitted through the middle ear and the principles of sound conduction that are involved Because of time limitations the discussion is confined to two topics, the mechanical operation of the middle ear, and the fidelity with which the middle ear performs

Of the peripheral structures the sensory cells of the organ of Corti are the most important To have hearing these cells must be vibrated, and to survive they must be nourished Because of their sensitivity to vibrations they cannot be nourished by any system that contains elements that might pulse or produce rapid movements through turbulent fluid flow, so we find these cells surviving without any direct blood supply but by being immersed in a fluid medium which moves imperceptibly, bringing nutrient material to the cells and carrying away waste products Hearing results when the desired vibrations are introduced into this fluid medium and are effectively transmitted to the cells

By placing a needle electrode in the vicinity of the cochlea and recording the potentials that arise from vibrations of the

## WEDNESDAY MORNING SESSION,

May 15, 1957

## PHYSIOLOGY OF HEARING

The International Conference on Audiology reconvened at 9 30 A M, in the Auditorium of the Washington University School of Medicine, St Louis, Missouri, Dr Harvey Fletcher, Director of Research, Brigham Young University, Provo, Utah, presiding as Chairman

DR FLETCHER We are to discuss today how the ear works, and the physiology of hearing The transmission of sound to the ear, through the middle ear, and into the cochlea, has been divided into two parts first, that part concerned with the process of sound conduction through the middle ear, second, transmission in the cochlea

## PROCESS OF SOUND CONDUCTION *

MERLE LAWRENCE,

University of Michigan,

Ann Arbor, Mich

Many of us involved in the field of hearing do research out of curiosity We would like to know how the ear works The clinical otologist, on the other hand, is interested in how the ear works because he would like to know what to do when infection or trauma interfere with normal function Specifically, he would like to know what certain steps that he might take would improve the performance of this disarranged mechanism, so the more basic knowledge revealed by the

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*From the Physiological Acoustics Laboratory University of Michigan Ann Arbor Mich Preparation of this report was supported by the Research and Development Division Office of The Surgeon General Department of the Army under contract No DA-49-007-MD-634 and by the funds for Research in Human Resources University of Michigan

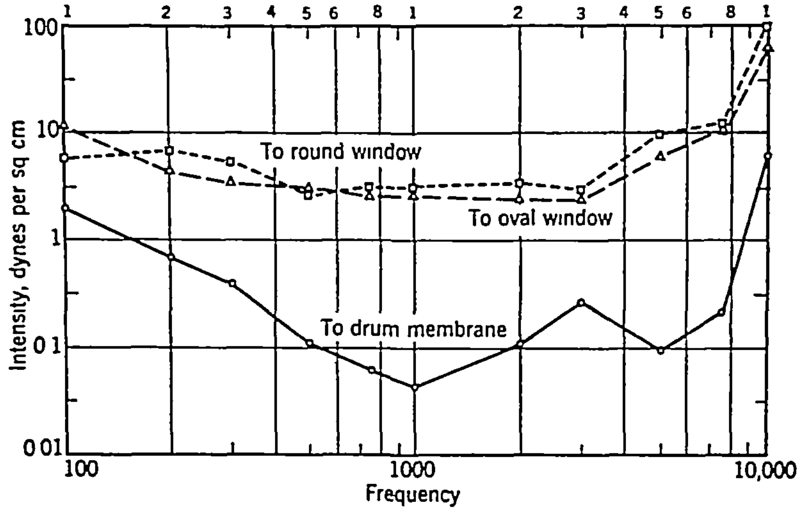

Fig 1 A comparison of oval-window and round-window pathways after the middle ear has been removed The ordinate shows the sound pressure necessary to produce 10 microvolts of response at the indicated frequencies 1 dyne/cm² is equivalent to 74 db above 0002 dyne/cm² From Reference 10

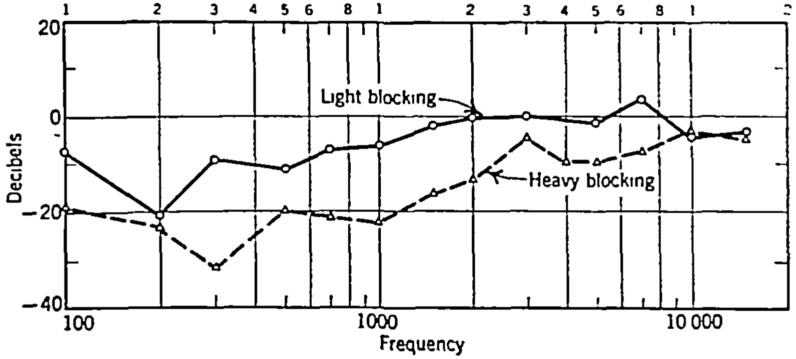

Fig 2 The effect of blocking the round window upon the response to sound delivered via the oval window From Reference 10

bubble one million times this size, about one-third of a cubic millimeter, would allow almost complete freedom of the fluid movements

Fig 2 presents the result of such an experiment The effects of two degrees of blocking are graphed to show something of the range of effects that can be obtained The decresensory cells, it is possible to obtain a measure of the efficiency of vibrations introduced into the inner-ear fluids Since there is no threshold or level of sound at which the potentials suddenly appear, it is necessary to use some constant voltage output in response to sounds of different frequencies as a measure of the ear's sensitivity By recording the sound pressure necessary to produce this pre-established level of response at the various frequencies in the normal ear, and comparing this with the responses under experimentally altered conditions, it is possible to obtain a quantitative measure of the effects of the abnormal conditions

For the purposes of simplifying the analysis of middle-ear function let us start with the condition in which there is no middle ear, the inner ear being bounded on the lateral side by the oval and round windows Our first concern is whether one of these air-conduction routes is more efficient than the other

Sound is first conducted by means of a small probe tube to the oval window and the sound pressure necessary to produce our pre-established response level measured by means of a calibrated probe-microphone system The sound is then conducted to the round window and these measurements repeated Fig 1 shows the result of such an experiment As is to be expected, considerably more sound pressure is needed to produce the required response when the middle ear is removed than when it is present, but it makes very little difference for effective vibration of the inner ear whether the sound is introduced into the oval window or the round window

Because the two windows lie at opposite ends of a fluid system, it has long been suggested that a back and forth movement of this fluid column is essential for sensory-cell stimulation This can be determined by carrying the above experiment a step farther While the sound is being introduced into the oval window the round window can be blocked This is a rather difficult thing to do effectively because the actual volume displacement of the fluids of the inner ear is so minute It amounts to the volume of a sphere with the diameter of a red blood cell when the ear is stimulated by a sound of 1000 c p s at 74 db above 0002 dynes/cm$^2$ An air pressure phase and pulling it out during the negative pressure phase If both windows are being pushed in at the same time the situation would be the same as blocking one of the windows, because no relief opening is available for either source of sound This condition is portraved schematically in Fig 4 It can be seen that in such a phase relationship no movement of the basilar membrane with subsequent sensory-cell stimulation is possible This is equally true of the phase

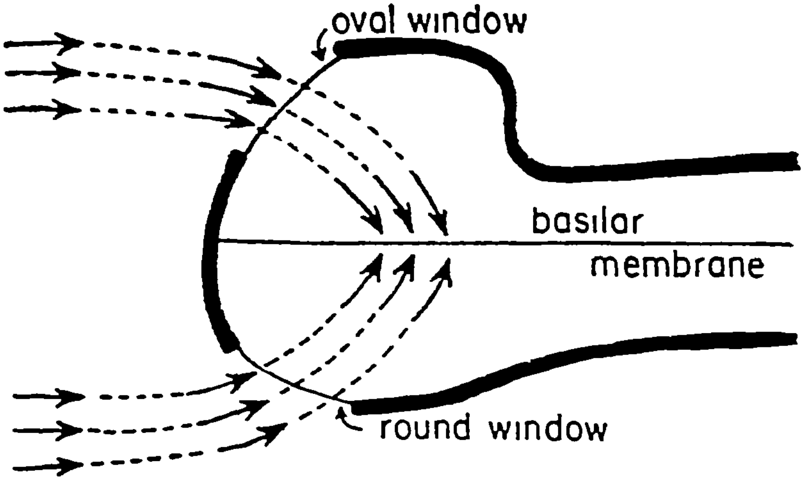

Fig 4 Schematic representation of sound entering both oval and round windows at the same time The phase condition represented here is such that there would be complete cancellation of response The sounds are in phase at the two windows and of equal intensity From Reference 11

relation when both windows are being pulled out at the same time, however, when one window is pushed in by a positive sound pressure and the other window is pulled out by a negative pressure brought about by delaying the sound by one-half a wave length, the effectiveness of the relief opening is enhanced By such a situation the amplitude of vibration of the basilar membrane should be double that produced by sound in one window alone

Again, by recording the electrical responses of the cochlea it is possible to obtain a quantitative measure of the above. Sound from one electronic oscillator is used with the output ment is greatest for the low frequencies, and is in excess of 20 db for those below 1000 c p s It is necessary to dry the surfaces and pack the niche completely with wax in order to produce the results shown It is apparent that the oval window pathway is effective only as long as the round window is free at the other end of the system

We find also that the oval window must be free to make the round window pathway effective Because of the presence of the footplate of the stapes it is easier to block the oval window than the round window, and by embedding the stapes in wax the results of Fig 3 are produced Now the effects are most severe in the range immediately above 1000 c p s, indicating that the method of blocking the two windows has changed the frequency response properties in different ways, but the principle is still demonstrated that in order for vibrations entering by one window to be fully effective in stimulating the sensory elements, the other window must be free to act as a relief opening at the other end of the system This was a theory first expressed by Edward Weber[8] more than a century ago

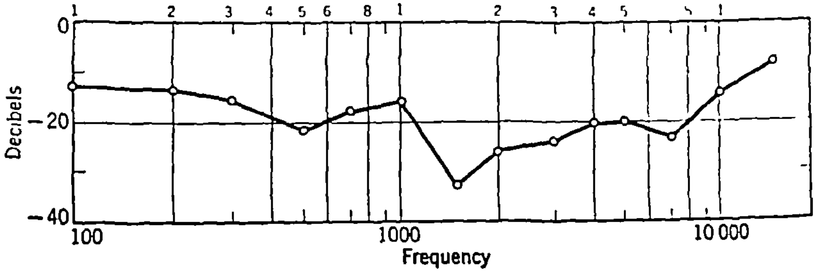

Fig 3 The effect of blocking the oval window upon the response to sound delivered via the round window From Reference 10

This principle can be studied more quantitatively if we introduce sound into both windows at the same time Such a situation would exist in an individual with no tympanic membrane or ossicles, so that both windows were exposed to the same sound field Visualize the alternating positive and negative sound pressure of a sound wave reaching one of the windows as pushing the membrane in during the positive the cochlear response as the phase of the sound in one window is shifted with respect to the phase of the sound in the opposite window The sound is first directed into one window alone and set at a sound pressure sufficient to give rise to a response of 10 microvolts This tone is then shut off and that directed toward the opposite window set to give a 10 microvolt response For the readings shown in the figure the tones are introduced into the two windows simultaneously The response shows what is to be expected from the vectorial sum of two sine waves of equal intensity when one is varied in phase As expected, in a phase relationship where one window is pushed in while the other is pulled out the response is double what sound in one window alone would give, and when they are 180 degrees from this condition, that is, both windows being pushed in or pulled out simultaneously, the response is completely cancelled The interesting thing to note is that as the phase varies through the complete 360 degrees, the two-window response is as good or better than that from one window alone over a phase difference of 240 degrees, while the two-window response is worse over only 120 degrees It is not likely that the sound, under conditions where both windows are exposed, hits them in the exact phase relation for cancellation In the first place the windows are not in exactly the same plane, considered from the point of view of the sound-wave front, and secondly, one window contains a stapes or footplate and the other a membrane These introduce phase differences, as will be shown shortly, and it does not take much of a phase shift to bring the response up to a level of that given by stimulation through one window alone If the two windows were exactly alike they would have to be separated by a distance of about seven inches for a frequency of 1000 c p s In the scheme behind our phylogenetic development this apparently was considered impractical

Another factor influencing this two-window summation is the intensity of the tones introduced Complete cancellation depends upon equal intensities, so this unwanted condition can also be avoided by the introduction of a more intense sound in one window than the other To accomplish this advantage has been taken of a fact which make a fluid-filled

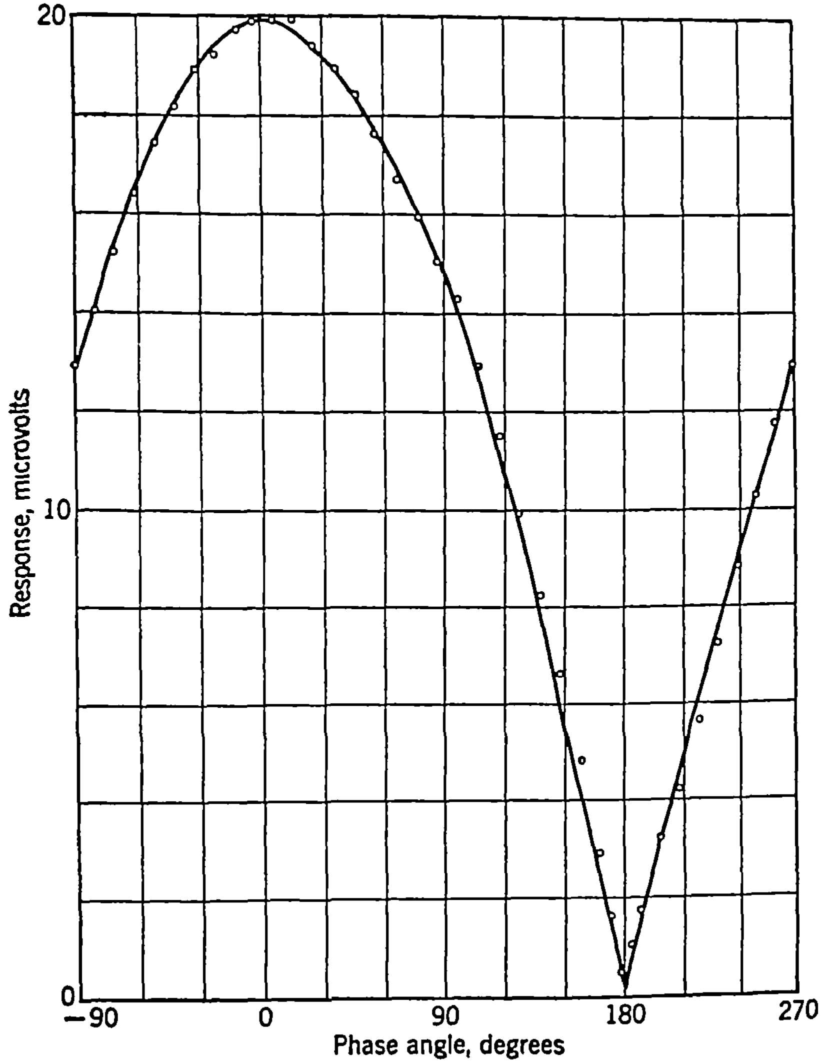

Fig 5 Vectorial summation in the cochlear response to a tone introduced simultaneously by way of the oval and round windows The phase relation of the two pathways was varied over a range of 360 as shown on the abcissa The points represent observations and the curve represents theoretical summation From Reference 10

passed through a dividing network Into one channel a phase changer is introduced and the two sources separately led, by means of small tubes, to each window The sound level is again recorded by a calibrated probe-microphone system, and the recorded electrical potentials serve as a measure of the effectiveness of the stimulus Fig 5 shows the magnitude of because of the resonant properties of the middle-ear structures, but the average is approximately 28 db, which is close to the theoretical loss of 30 db It means that, considering the errors which can be attributed to the nature of the experiment, the middle ear of the cat is almost perfectly efficient

Since the time of Helmholtz much research and thought have gone into the problem of how the middle-ear structures accomplish this match Of the theories of action that have been proposed, two have been shown experimentally to contribute to the impedance matching process

The first of these depends upon the *areal ratio* between the tympanic membrane and the footplate of the stapes In man the average of the available data shows this ratio to be about 21 to 1 Considering the fact that the tympanic membrane is not like a piston, but rather like a stretched membrane attached around the edge, the effective area of the membrane must be reduced by about one-third, making the ratio 14 to 1

The second characteristic of the middle ear that aids in the matching process is the *lever ratio* brought about by the peculiar arrangement of the ossicular chain Measurements of this in the human are few and probably not very accurate Dahmann[3] made what are probably the most reliable measures, by placing small mirrors on the drum membranes and then on the long process of the incus The ratio so determined was found to be small about 1 3 to 1

The product of the areal ratio and the lever ratio give us the transformer ratio of the entire middle ear, which then amounts to approximately 18 to 1 This pressure increase at the footplate of the stapes is equivalent to 25 db, which is not enough to overcome completely the theoretical loss of 30 db , but these figures should not be taken too seriously because of the limitations in both the experimental data and theoretical calculations In calculating the theoretical 30 db loss in the passage of sound from air to the fluids of the inner ear, data for boundless media were used, whereas the air of the middle-ear cavity or fluids of the inner-ear space are far from boundless On the other hand, data used to determine the areal ratio are limited, and the data of the lever ratio may ear quite impractical in an air environment, as was the case some 250 million years ago, when the predecessors to the amphibians first found themselves on land

Because of the extreme differences in the properties of elasticity and density between air and liquid, approximately 99 9 per cent of the acoustic energy is reflected back at an air-water interface This means that there is a loss of 30 db in transmitting the vibratory energy from the air to the inner-ear fluids By the use in one window only of a mechanism that matches these properties of air and water, it is possible to overcome both of the disadvantages of the two-window

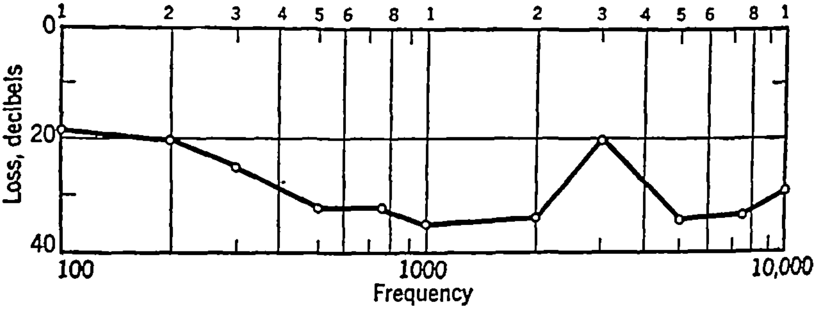

Fig 6 The loss of sensitivity resulting from the removal of the middle ear mechanism in the cat From Reference 10

fluid system *1* the cancelling effect of equal-intensity, in-phase sound entering by the two windows is overcome by increasing the intensity in one window by 30 db over that in the other, *2* the loss in transmitted energy due to the air-liquid interface is overcome by matching the properties of air to those of the denser liquid, and this apparently is just what the middle ear does

To see whether the middle ear is actually performing this function, and if so, how efficiently it is accomplishing the impedance match, we can again resort to an animal experiment, recording the electrical responses of the cochlea under conditions in which the ear is normal and those in which the middle ear is removed Fig 6 represents the loss, in the cat ear, resulting from removal of the middle ear structures up to the stapes The loss is not the same for all frequencies, structures by a tone of the same frequency, but adjustable in intensity, applied through the round window A determination of the current in the cancelling receiver gave a measure of the volume displacement He then repeated the balancing process after removing all of the middle-ear structures, including the stapes and round window, by conducting the sound directly to the fluids of the inner ear through the oval and round window openings These results showed considerably larger volume displacements at low frequencies than before, but their magnitude showed a progressive decrease as the frequency was raised until, at the higher frequencies, they became smaller than in the intact ear

Fletcher[4] divided the first set of values by the corresponding ones in the second set, and regarded the quotient as representing the transformer ratio of the middle ear The calculations, which he interpreted as demonstrating a middle-ear pressure reduction for frequencies below 650 c p s, are presented as curve *a* of Fig 8 He saw advantages in this sort of action in that the system would discriminate against disturbing low frequencies, and on the basis of this it has been suggested that the middle ear does not at all act like an impedance-matching transformer, however, in this same series of experiments, Békesy made some other measurements that more accurately reflect the action of the middle ear In this instance the second measurements were made with the drum membrane and outer ossicles removed but with the stapes left in the oval window and with the round window membrane intact

When the values of volume displacement for the intact ear are divided by those for the above conditions we have a curve, *b* in Fig 8, that is in better accord with the earlier results and testifies to a useful transformer action of the middle ear for all frequencies

It is obvious from these determinations, and those showing the contribution of the middle ear to sensitivity, that the advantages are not the same for all frequencies The middle ear is not a truly high-fidelity device, but it does remarkably well Three forms of distortion, found in all forced-to-not be very accurate because of the difficulty of determining accurately from an optical lever the excursion of a vibration when the axis of rotation of the mirrors is not known, nevertheless, the figures are close enough to indicate that the principles described are the right ones

Measurements of the transformer ratio, which have been made on human cadaver material, show that these figures are fairly accurate Bekésy[1] drained out the fluid of the inner ear, dissected away the cochlea, and then applied sound to the inner surface of the stapedial footplate This he adjusted in intensity and phase so as to cancel the effects of another sound of the same frequency introduced at the drum membrane A capacitative probe near the surface of the stapes showed when cancellation was complete From these he obtained a transformer ratio of 10 at 100 c p s , rising to 18 at 2200 c p s and then rapidly falling This is shown in Fig 7 Now the lever ratio and areal ratio of the middle ear will not change with frequency, so the variations in the transformer ratio can probably be attributed to the influence of the inherent response properties of the ossicular chain

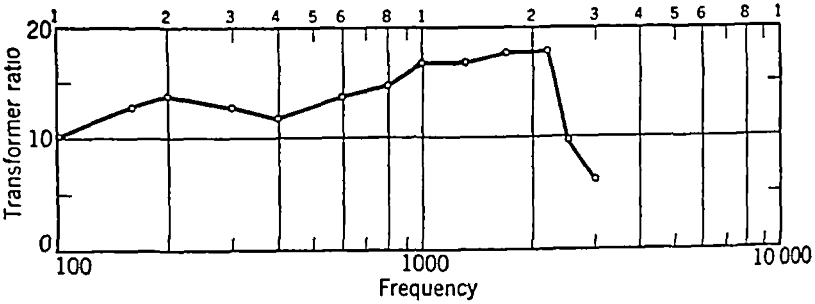

Fig 7 The transformer ratio of the human (cadaver) ear according to Bekesy[1] From Reference 10

At this point we must mention some other interpretations made on the basis of another experiment reported by Békésy in 1942[2] In this instance he measured, also on cadaver specimens, the volume displacement of the round window for a number of conditions In the first of these he cancelled out a tone applied to the inner ear through the intact middle-ear

Fig 9 shows the phase shift introduced for frequencies from 100 to 10000 c p s by the entire middle ear Positive values indicate a phase lag introduced by the ossicular chain The amount of phase variation is quite moderate for frequencies below 5000 c p s , and then grows greater and more variable for the higher frequencies Actually these phase changes remain constant at the different frequencies and so, of course, make no noticeable difference to hearing Since the sound being transmitted by this route to the oval window is more intense by about 30 db than that reaching the round window, any inner-ear effects due to the phase difference are negligible When the middle ear is removed, however, so that this advantage is lost, any phase shift in one window relative to the other makes a great deal of difference, as was described earlier

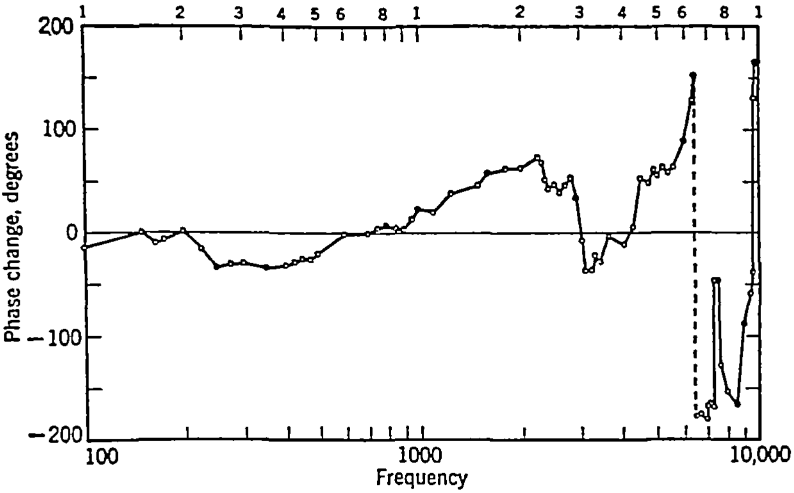

Fig 9 Phase changes produced by the entire middle-ear apparatus Positive degrees represent a retardation of phase. From Reference 10

Measurements made of phase changes attributed to action of the stapes are shown in Fig 10 These variations are small, never exceeding 15 degrees below 5000 c p s , but as shown in Fig 5 it takes very little shift from the cancellation point to improve the situation This demonstration of the vibrate devices, that have been extensively studied in the middle-ear response to acoustic vibrations are frequency, phase and non-linear or amplitude distortion

The first of these, frequency distortion, is illustrated in Fig 6 This curve represents the frequency response for the middle ear of the cat Like any other device, when forced to vibrate, it exerts its own resonance properties into the vibration and so alters the frequency characteristics In the human ear this middle-ear frequency distortion is reflected, along with many other hearing phenomena, in the sensitivity curve

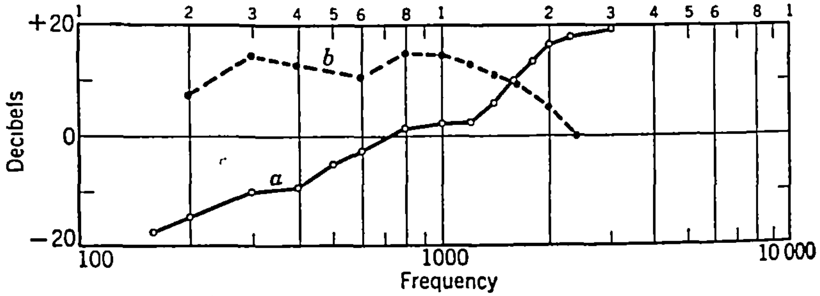

Fig 8 The pressure amplification afforded by the middle-ear mechanism as derived from the observations of Bekesy Curve *a* shows the results of Fletcher s computations and curve *b* those of Wever and Lawrence[10]

Whenever there is frequency distortion due to the characteristic mass and stiffness properties of the driven structure, phase differences are also introduced into the vibratory response This means that as the sound at the tympanic membrane reaches a positive-pressure peak or a negative-pressure peak the ossicular chain lags behind or, in fact, may appear to precede the movements of the air-borne vibration Thus the chain of middle-ear bones introduces phase distortion, not only by shifting the phase but also by doing it differently and in varying amounts over the frequency range

By employing a stimulating system similar to that described for studying the effects of different phase relations at the oval and round windows we can find out how much the middle ear shifts the phase for various stimulating tones

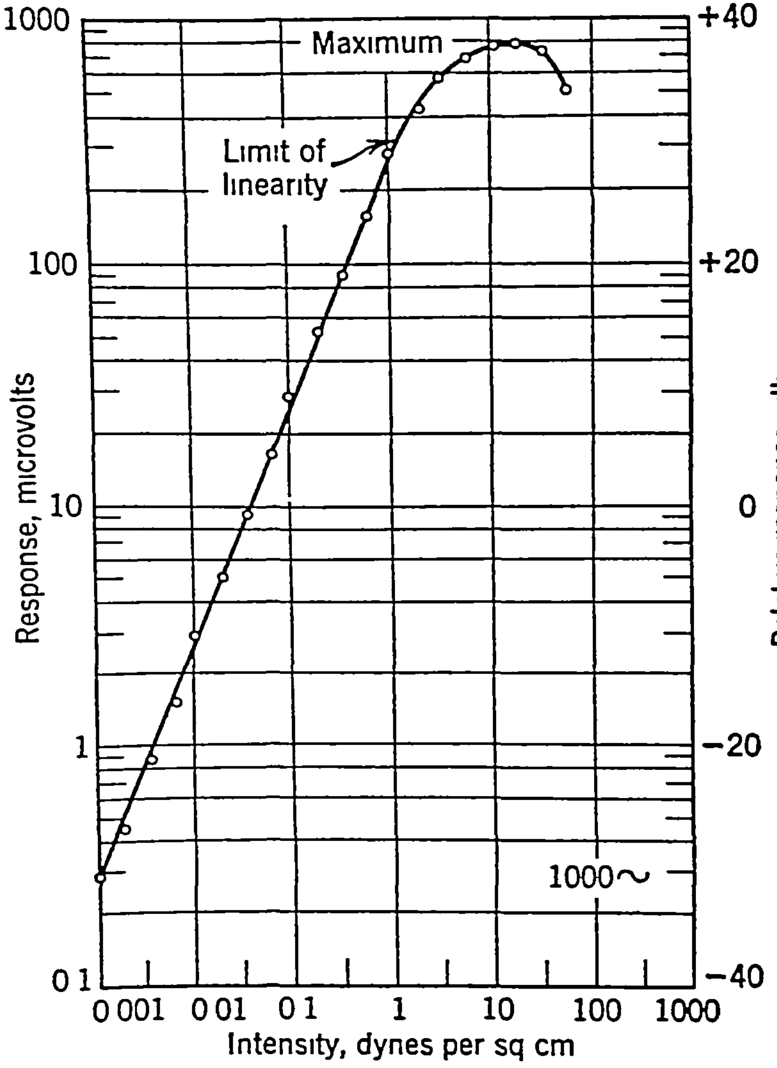

Fig 11 The intensity function for the cochlear response recorded from the round window of the cat. The limit of linearity denotes the point in the response where it is no longer proportional to changes in the stimulus intensity From Reference 10

vibration is transformed into the recorded electrical response We would like to know then, what structure or process brings on this departure from linearity and specifically, for our discussion here, we would like to know whether the conduction process in the middle ear is responsible for this phase characteristics of the stapes serves to emphasize the importance of establishing a favorable phase relationship between the two windows during any reconstructive surgery of the middle ear performed for the purpose of improving the hearing

The third type of distortion concerns the ability of the structures to follow increases in amplitude of the driving

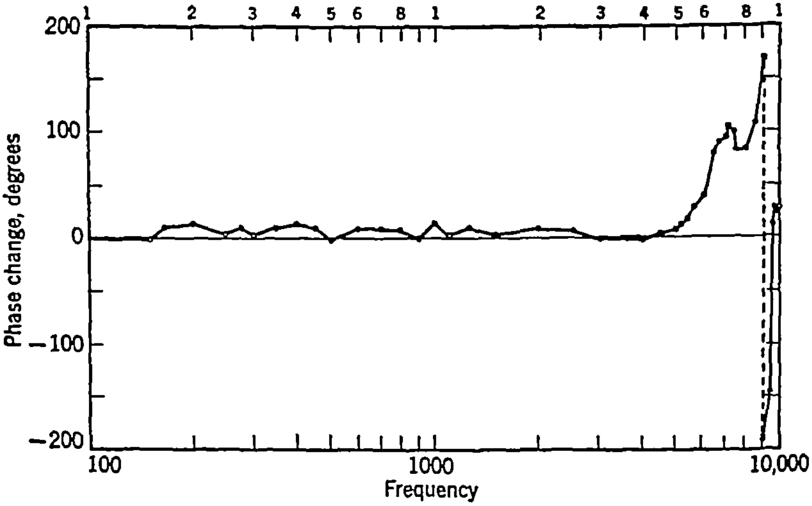

Fig 10 Phase changes produced by the stapes Positive degrees represent a phase lag in the oval-window pathway relative to the round-window pathway From Reference 10

vibration A characteristic of the electrical response of the cochlea in response to a pure tone is that as the sound amplitude is increased the electrical output increases proportionally over a characteristic range, and then departs from this straight-line function until finally it reaches a maximum The point at which the response becomes no longer proportional to the amplitude increases of the stimulating sound is called the "limit of linearity," and the point at which there are no increases in response to further increases of stimulus is called the "maximum," as shown in Fig 11 The electrical response recorded in this instance reflects not only the transmission of sound through the middle ear and through the fluids of the inner ear, but also the process by which this

The evidence gathered over the last few years has shown conclusively that the inner ear is responisble for this early departure from a linear response One way to study this is to record the magnitude of the electrical response as well as its wave shape, and compare this to the wave shape of the stimulating sound and that of the sound after it has been relayed by the ossicular chain to the fluids of the inner ear and escapes from the round window A comparison is made in Fig 12 The wave shape of the sound coming from the round window is still undistorted to a level of stimulating sound that has brought about severe wave form distortion in the electrical response If distortion had occurred in the middle ear this would have been transmitted through the fluids to the round window

Another test for the locus of this amplitude distortion has been made by applying a vibrator, first to the umbo of the malleus then to the head of the stapes, and recording the cochlear response in both instances If the middle ear is responsible for this type of distortion, departure from linearity should occur at a lower response level when the middle ear is present than when it is removed Results are shown in Fig 13 The limit of linearity occurs at the same response level for both methods of stimulation, indicating that the middle ear is not responsible Since the middle-ear lever, which reduces stapes amplitude while increasing pressure is removed in one instance, the response through the stapes alone is greater for equal sound pressures than the response after traversing the ossicular chain

It is true that if the middle ear is driven hard enough it, too, will become non-linear but not until a level of sound has been reached that would have destroyed the inner ear, and nothing seems to affect this ability of the middle ear to respond linearly over a considerable range of sound intensities The middle ear can be filled with fluid or the stapes ankylosed and, although sensitivity is lost, the middle-ear dynamic range is very little affected

In the process of conducting sound from the external meatus to the fluids of the inner ear the tympanic membrane and ossicular chain do not only an amazingly efficient job of

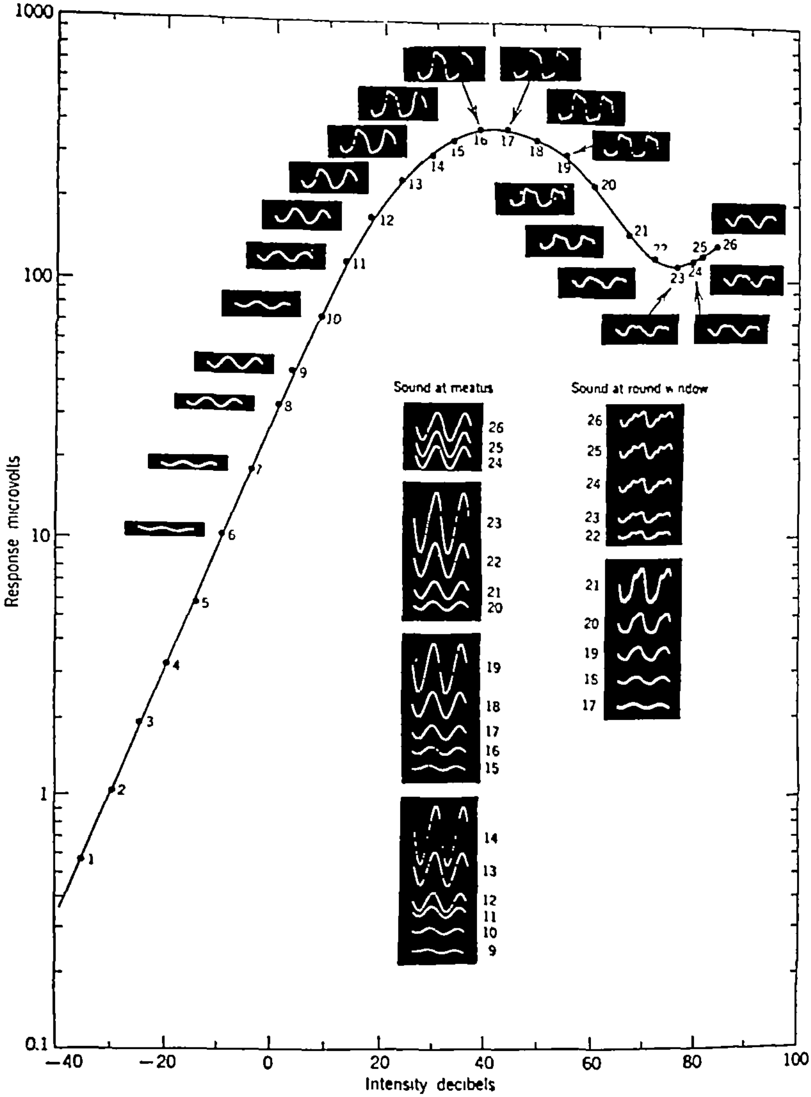

Fig 12 The intensity function for the cochlear responses of the cat's ear with a display of wave forms of this response at different levels The intensity scale is in decibels relative to 1 dyne/cm (74 db above 0002 dyne/cm ) The points of measurement along the curve are numbered and from 6 on each has adjacent to it an oscillogram of the cochlear response obtained For these waves the amplification of the oscillograph was constant up to point 9 and then was reduced and held constant thereafter for points 10 to 26 In two columns below are oscillograms for some of the sounds entering the ear at the meatus and also for sounds picked up from the round window In recording these sounds the amplification of the oscillograph was constant for each block of pictures but was varied between blocks From Reference 10

matching the properties of air to those of the dense perilymph so as to introduce sound with a minimum of loss, but do so over a wide range of frequencies with no amplitude distortion within the range of inner-ear response and with tolerable frequency and phase distortion

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# DISCUSSION OF DR LAWRENCE'S PAPER ON "PROCESS OF SOUND CONDUCTION"

HENNING E VON GIERKE *

The starting point for any serious discussion is a point of disagreement, of doubt, or a question mark It would be very hard to pick out such a point from Dr Lawrence's excellent presentation I think it became quite clear from his

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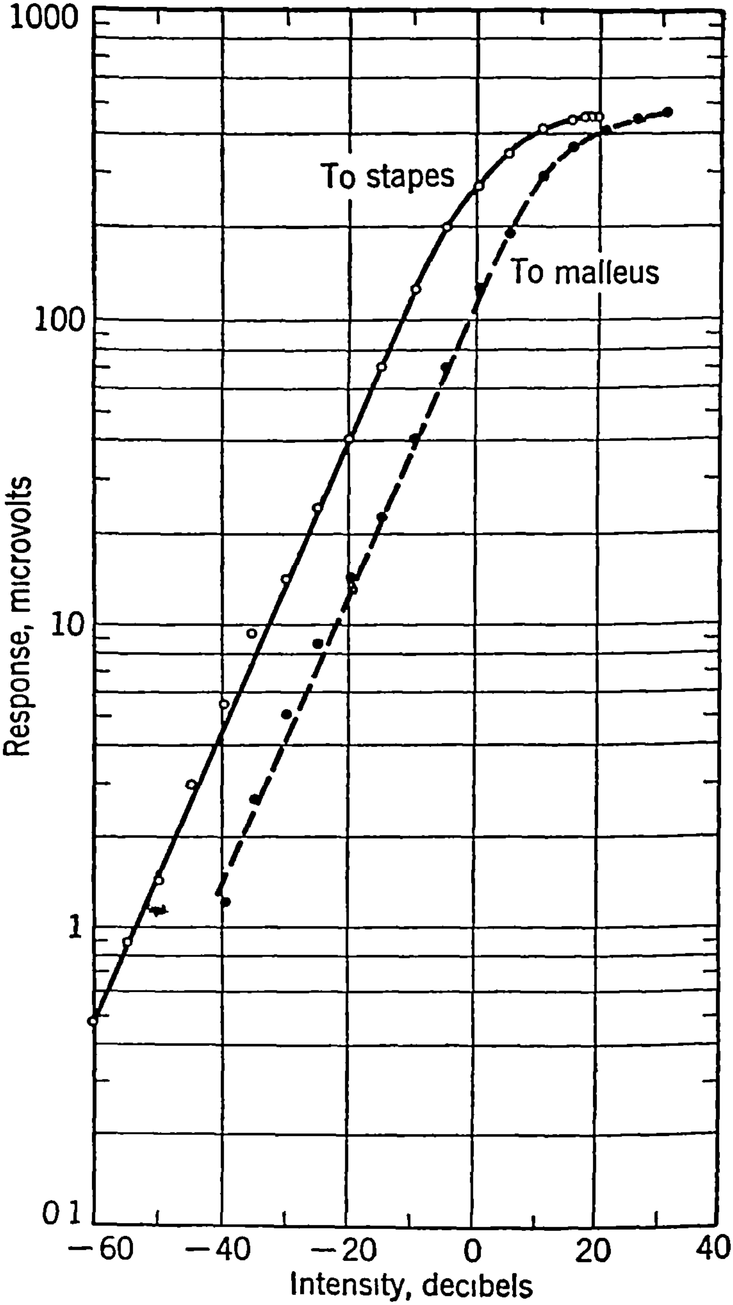

Fig 13 The cochlear response recorded from the round window in response to mechanical vibration at a frequency of 1000 c p s of the stapes and the malleus The limit of linearity occurs at the same response level in both instances From Reference 10

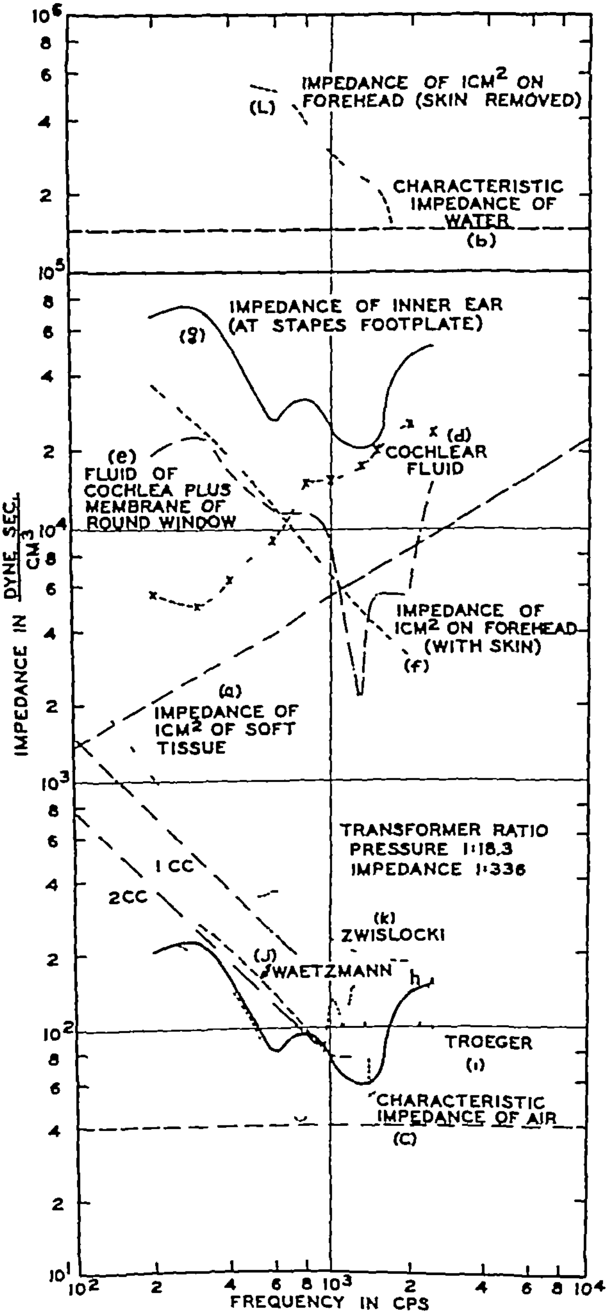

Fig. 1 Impedance Values Measured at Various Locations in the Ear and on the Body Surface—a Impedance of area (1 cm²) overlaying soft tissue (upper arm), b characteristic impedance of water c characteristic impedance of air, d impedance of cochlear fluid e impedance of cochlear fluid plus membrane of round window f impedance (area 1 cm²) of the forehead (with skin) g impedance of the inner ear measured at the footplate of the stapes h inner ear impedance as appearing at the tympanic membrane (curve g transformed by the middle ear) i-j-k impedance values measured at the tympanic membrane l impedance measured on the forehead without skin (area 1 cm²)

presentation that our physical understanding of the conduction mechanism is fairly good, that we are in the position to give average quantitative numbers to the different components of the transmission system, and that in this part of the auditory mechanism the various hypotheses have been almost completely replaced by measured facts This does not mean that there is not much room left for very worthy and interesting refinement It simply means that there are no big surprises waiting to be discovered

Let me add a few words to refine our picture of the physical purpose of the middle ear Since the acoustical properties of human tissue are very close to the acoustical properties of water, a very simplified statement of the middle ear's task is that it has to match the impedance of air to the impedance of water (Under impedance we understand the ratio of the driving sound pressure to the velocity of the resulting motion, a measure of mobility Depending on the phase between pressure and velocity, the impedance can be a mass reactance, an elastic reactance or a frictional resistance, or a combination of these three elements ) This impedance of water or tissue is a well known constant only if we have undisturbed sound propagation in an almost infinitely large medium This is practically never the case for sound in tissue and, therefore, the impedances of the middle and inner ear do not so much depend upon the acoustical constants of the tissue as they do upon the geometrical shape and the boundaries of the elements involved For example, a blocking of the round window with an otherwise completely intact conduction mechanism would change the impedance or mobility at the oval window considerably, and consequently also the impedance at the tympanic membrane

To illustrate this point, impedance values measured at various locations in the ear and on the body surface are shown in Fig 1, together with the impedance of an infinite water or air medium Curve *a*, represents the impedance of a small circular area (of approximately the same size as the tympanic membrane) at the surface of soft tissue, as measured over soft muscle and skin[6] It is mainly a mass reactance, increasing with frequency We see that this impedance is volume of this cavity, we measure impedances of the general shape indicated in Fig 1 by the impedances for air volumes of one and two cubic centimeters Only here in this region, where the middle ear increases the transformed inner ear impedance, the middle ear transformer does not act as an "ideal transformer"

This elasticity of the middle ear cavity, together with the elasticity of the tympanic membrane itself are the reasons why the impedance measurements at the tympanic membrane have only limited value for diagnostic purposes, not all acoustic energy received by the tympanic membrane is conducted to the labyrinth On the other hand impedance measurements are almost the only objective examination method available to make a real measurement of the sound conduction mechanism *in vivo* It is regrettable that so far this method has never been refined and improved, so that it could be clinically applied to those cases for which its usefulness has been proven in principle the diagnosis of conduction impairments[3]

On Fig 2 the absorption co-efficients resulting from the impedance values of Fig 1 are shown The absorption co-efficient indicates the percentage of the incident airborne sound energy that is absorbed by the tympanic membrane (Curves *a* *b* *c*) and conducted to the inner ear, or absorbed by soft muscle tissue (for example upper arm, Curve *d*) or bone (Curve *e*) Curve *f* indicates how little energy of a plane airborne sound wave is transmitted through a boundary between air and water It should be noted here that in many cases, as Metz[3] has shown, conduction impairments in persons having normal tympanic membranes are detectable by a decrease of the absorption co-efficient measured at the tympanic membrane

The absorption co-efficient shown in Fig 2 for bony structure, Curve *e* can hardly be used to calculate the threshold of bone conduction It gives only the energy absorbed by the surface of the forehead, and does not tell us how much this energy is attenuated in the bone on its way to the inner ear Most of this energy is already absorbed in the skin and not transmitted to the bone itself, therefore, whereas the energy absorbed at the tympanic membrane, Curves *a*, *b*, *c*, is, at considerably below the impedance for plane compressional waves in water, Curve *b*, which is so often cited as the approximate impedance of tissue to which the middle ear transformer has to match the impedance of the air, Curve *c* The reasons for the difference between Curves *a* and *b* are not so much the differences in the properties of tissue and water, but they are the boundaries of the medium and the type of wave propagation set up in it Over the whole audio-frequency range we hardly ever find compression waves in the body tissue, we always have shear waves and surface waves, which have different propagation velocity, absorption and wave length[6] I think this fact cannot be stressed enough in discussing propagation of sound waves through tissue. Let us now look at the impedance of the cochlear fluid alone, Curve *d*, as measured by von Bekesy[5] We see this impedance is quite similar to the impedance of soft tissue If we add to this fluid the elastic membrane of the round window we observe on the resulting impedance, Curve *e*, the following For the lower frequencies the elastic component determines the impedance,* and this impedance is very similar to the impedance of other bony structures of the body As an example, the impedance measured on the forehead is plotted as Curve *f*[1,2], so we see the impedance values of the cochlea are of the same order of magnitude as the impedance of other body tissues The impedance measured at the footplate of the stapes, given by Curve *g*, was obtained by von Bekésy[5] If we now multiply this impedance with the square of the pressure transformation ratio of the middle ear, as discussed by Dr Lawrence, we obtain, as the impedance at the tympanic membrane much lower values of the impedance, Curve *h* These impedance values, calculated from measurements on human cadavers, agree very nicely with the impedance measurements (Curves *i* *j*, *k*) made *in vivo* at the tympanic membrane by several investigators[4,8,9] Only at low frequencies is the impedance measured at the tympanic membrane determined by the impedance of the tympanic cavity which exceeds the transformed impedance of the inner ear, Curve *h* Depending upon the to the inner ear by bone conduction, is approximately 50 to 60 db below the air conduction threshold In Fig 3 some hearing threshold measurements are shown when the sound stimulus was exciting different areas of the body[7] The data are plotted with reference to the air conduction threshold It is remarkable how relatively little difference one observes in stimulating different areas of the body This indicates that the main loss occurs at the transition surface

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*Some of the statements made here about the phases of the impedance i e if they behave like masses or elasticities are not direct conclusions from Fig 1 but follow from the original investigations

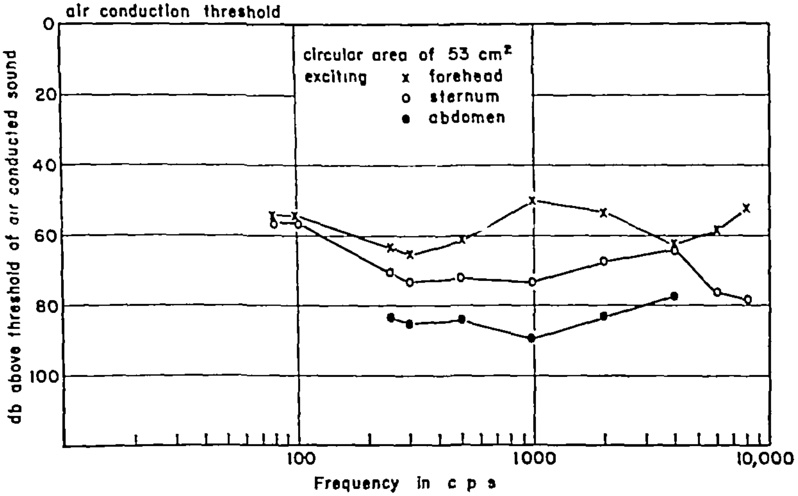

Fig 3 Threshold of hearing for airborne sound received by different areas of the body relative to the air conduction threshold

I do not want to go deeper into the problem of bone conduction here, and I think it was no accident that Dr Lawrence omitted details on it It is actually deplorable how little exact physical information we have about the bone conduction pathways in the tissue and about the details of how the bone conducted sound acts on the cochlea Since it has been shown that impedance and skull resonances, measured on skull preparations, can be related reasonably well to *in vivo* measurements, such measurements should be possible with electro-acoustic methods and tools

The physical description of the mechanical conduction mechanism is not solved until we can describe the stimulus delivered to the electro-mechanical transducers Von Bekésy's[5]

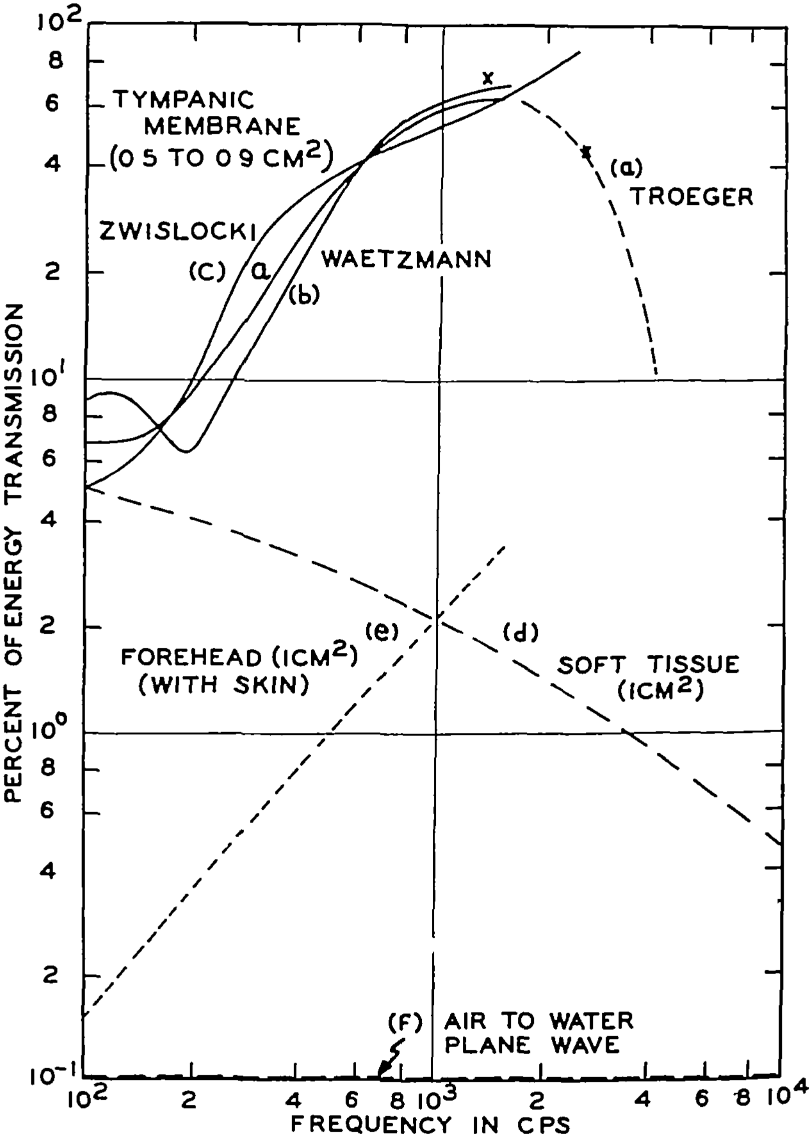

Fig 2 Acoustic energy transmission through the tympanic membrane and other human body surfaces in per cent of incident sound energy

least at the higher frequencies, almost completely transmitted to the cochlea, roughly only 1/1000 or less of the energy received by the forehead reaches the inner ear This explains why in a free sound field our threshold for airborne sound, received by body areas other than the ears and transmitted which supports the organ of Corti  Any hindrance to the passage of sound waves down the external auditory meatus, across the ossicular chain of the middle ear cleft to the oval window, and finally through the labyrinthine fluids to the basilar membrane, will cause an impairment of hearing even though the organ of Corti and VIIIth nerve are normal, furthermore, the degree of deafness is a measure of the effectiveness of the block which may be such that air borne sound waves are prevented from reaching the organ of Corti

A simple plug of cerumen in the external auditory meatus, particularly if it hinders the free excursion of the tympanic membrane, deserves pride of place as the commonest cause of conductive deafness  An effusion into the tympanic cavity, a vacuum within the middle ear space due to Eustachian insufficiency, or solid matter in the shape of adhesions or growth may also impede the transmission of sound, but the most effective, and next to cerumen the most common cause of conductive deafness, is found when there is an interference with the normal mechanism whereby sound waves enter and leave the labyrinth by means of the oval and round windows In the Eighteenth Century Valsalva, Morgagni and Meckel all recognized stapes ankylosis as a cause of deafness, and late in the Nineteenth Century Politzer gave it the name otosclerosis

More recently it has been appreciated that any interference with the normal phase relationship between the oval and round windows may affect the transmission of sound to the inner ear  This may happen if the ear drum is perforated so that the incoming sound waves fall more or less simultaneously on the two windows, thus cancelling each other out The reason why the earlier operations for the relief of deafness due to otosclerosis by means of an opening into the lateral semi-circular canal were so rarely rewarded by success is that the operated area was closed up so that incoming sound waves fell with more or less equal and simultaneous pressure, both on the round window and on the new window in the lateral semi-circular canal

Sourdille was the first to devise an open operation so that the incoming sound waves were free to pass through the new observations, and his measurements of the mechanical constants of the cochlea, gave us the physical understanding and led to the theories describing the mechanics of the cochlea in general terms Finer, but also important, details like the location and cause of nonlinear distortions and the mechanical energy *finally* transmitted to the hair cells are still very far from a solution It looks as though a new tool must be found to obtain access to these dimensions, and this tool might well be the electrical activity of the inner ear itself Dr Lawrence's discussion of the distortion problem and the investigations we are looking forward to hearing about from Dr Davis and his co-workers, indicate that further understanding of the electrical potentials might give us the tools to make another step ahead in measuring the mechanical conduction mechanism

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## SOME CLINICAL FEATURES OF SOUND CONDUCTION

Terence Cawthorne,

London, Eng

The sound conducting part of the auditory mechanism extends from the side of the head to the basilar membrane than to irreversible degenerative changes in the cochlea or VIIIth nerve

In support of this view it may be mentioned that in many of these patients with so-called "mixed deafness," the response to speech, providing that it is loud enough, is the same as in uncomplicated conductive deafness, whereas we know that in most cases of end-organ or nerve deafness the response to speech is quite different I do not believe that in advanced otosclerosis the organ of Corti or the cochlear nerve are, because of certain conventional tests, necessarily at fault The acid test in all these advanced cases is whether they are able to understand amplified speech So long as they can do this there is reason to hope that the organ of Corti will respond to any sounds that are able to reach it

Now for another aspect of the conduction of sound waves, this time within the labyrinth I refer to the Tullio phenomenon, which relies for its effect upon a vestibular response to an acoustic stimulus Tullio originally produced this effect by making an opening into the lateral semi-circular canal of pigeons, and then observing that in response to a loud sound there was a typical vestibular response of the eyes and the head

Just before the War, I made an opening into the semicircular canal of a patient with Menière's disease The stapes was free to move, and the labyrinthine structures were intact The following short extract of a film taken in 1939 shows what happened The small light attached to the earphone lights up when a sound of 80 db is on It will be noticed that on the unoperated side nothing happens when the bulb lights up, but on the operated side it is followed by a deviation of the eyes and head You may well ask, why does this not happen after every fenestration operation? The reason is that the stapes is not free to move If it were, and I have seen it in patients who were submitted to a fenestration operation for perceptive deafness when the stapes was mobile, then this distressing effect is seen—distressing because in several cases I have had to destroy the labyrinth in order to relieve the patient of troublesome vertigo window in the lateral canal, while the round window was shielded by the tympanic membrane Sourdille's multi-stage procedure was simplified and improved by Lempert, whose fenestration operation has become the standard surgical procedure for the relief of deafness due to otosclerosis Once the sound waves have entered the labyrinth they may be hindered by abnormal conditions of the fluid therein It has been suggested that the variable low tone deafness in Meniere's disease is due to the increased pressure of endolymph interfering with the proper excursion of the basilar membrane

One of the problems facing the aural surgeon when an otosclerotic patient presents himself hopefully as a candidate for fenestration, is to estimate the chances of success Obviously if the organ of Corti itself is also defective, no operation to enable sound to re-enter the labyrinth, no matter how well it is carried out, will help if the organ of hearing is incompetent In consequence surgeons have been chary of operating on any patients who exhibit any of the classical signs of perceptive deafness

Now, as the movement of the stapes footplate in the oval window in response to sound becomes more limited as the otosclerotic bone spreads, a time must surely arrive when it will move hardly at all, even in response to powerful acoustic pressures The effect of this will be to prevent the transmission of sound waves through the oval window With only one window working but little effective sound is likely to reach the end-organ of hearing, and in consequence signs of cochlear insufficiency will be added to those of defective transmission, even though the cochlear end-organ is intact and ready to respond to any sound which may be permitted to reach it Most of us have been brought up to believe that in advanced otosclerosis cochlear changes take place Stacy Guild has shown that in the temporal bones of advanced otosclerotic deafness which he examined, there were no more histological changes in the organ of Corti and VIIIth nerve than could be accounted for by age, therefore, it seems to me that we must revise our view of advanced otosclerosis and regard the profound deafness as being due to inability of sound to reach an otherwise normal organ of hearing rather

Dr Heinrich G Kobrak, Wayne University School of Medicine, Detroit, Michigan, presented a film on sound conduction in the ear Unfortunately, due to his unexpected death a description of the film is not available

# TRANSMISSION AND TRANSDUCTION IN THE COCHLEA *

HALLOWELL DAVIS,

Central Institute for the Deaf,

St Louis, Mo

My portion of our symposium deals with the cochlea as a sense organ The domain extends from the oval window to the internal auditory meatus Dr Lawrence has told you how sound is conducted to the inner ear, and Drs Galambos, Tasaki, Neff and others will pick up the story of the nerve impulses that emerge from it

My story breaks into two major parts the first is *acoustic analysis*, the second is *neural excitation* These follow one another logically in the sequence of transmission and then transduction They also follow in the order in which they have commanded scientific interest in the past and in regard to the extent of our present knowledge and understanding Each part is primarily concerned with one of the two major dimensions of the acoustic stimulus Acoustic analysis is concerned with how information concerning *frequency* is "coded" for transmission This has been the historic and almost exclusive subject of the "auditory theory" of psychologists, but personally, as a physiologist, I am now even more interested in how, regardless of frequency, the ear can encompass its tremendous *dynamic range*, how it can respond to movements of its tympanic membrane of sub-molecular amplitudes, whether there is a biological amplifier that stands between the movements and the nerve impulses, and, if so, how it operates

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*Prepared under Contract N6onr 272 (03) between Central Institute for the Deaf and the Office of Naval Research Reproduction in whole or in part is permitted for any purpose of the United States Government.

One final word about the footplate of the stapes in otosclerosis I have tested its mobility at operation using the dissecting microscope in many cases, and I have also inspected the round window niche

In very advanced cases of otosclerosis with profound deafness, the footplate and the distal part of the crura may be literally buried in otosclerotic bone, and occasionally I have found the round window niche also to be blocked by otoscerotic bone On the other hand, in patients whose deafness is not so severe there is often some movement in the stapes, and I have been able to observe movement of the round window in response to pressure on the stapes

In the Wernher Research Unit on Deafness at King's College Hospital Dr Littler and I have been trying to measure the impedance of the stapes in otosclerosis, and this work is still in progress

Regarding the relatively new procedure called mobilization of the stapes, which has been recently re-introduced by Dr Rosen of New York, this is arousing great interest everywhere, and there is no doubt that it works in a proportion of cases My impression so far is that it is most likely to be successful when the hearing loss for pure tones does not exceed 50 db, and being such a slight procedure, it can be justifiably recommended when only one ear is affected An important point is that if it is unsuccessful it does not in any way prejudice the chance of a subsequent fenestration operation Though it is a minor operation from the patient's point of view it is far from easy, and I feel that those who practice it should also be prepared to go through with a fenestration operation subsequently, should it not succeed

New and beautiful plastic operations for the repair of perforated ear drums, and for the restoration of the ossicular chain on ears damaged by former infection, reported by Zolliver and Wullstein, are attracting much attention, also the provision of an external meatus and middle ear for children born with aplasia of the sound conduction mechanism is now an established procedure single nerve fiber The overall task of the cochlea is to match this many-channeled single-valued communication system to the single continuously-variable channel of the open air, and then to code the particular acoustic signals in terms of patterns of nerve impulses (I hope that Dr Licklider will tell you whether I have used Prof Gabor's terms "matching" and "coding" correctly, and also how modern auditory theory combines the place principle, the frequency principle, and the all-or-none principle )

Several secondary principles, or propositions of physiology and biophysics, can be added in describing cochlear actions Some are old, some are new, but all have been greatly illuminated by recent anatomical studies or physiological experiments A few of these I shall discuss with you to the extent that time permits One of these will be the complexity of the fine movements of the cochlear partition Békésy has visualized them and finds them far more complicated than we had previously assumed Likewise the electrical responses are more varied and more complex They include not only the familiar cochlear microphonic but also one and probably two DC responses to AC stimulation The ear acts as an acoustic rectifier and integrator, and the "summating potentials" are the electrical signs of this action The endolymph has a unique chemical composition, and the endolymphatic space is strongly charged electrically relative to its surrounding tissues, but we shall hear evidence tomorrow that these unusual properties are not dependent upon one another We can now see anatomical details of hair cells, nerve endings and supporting cells to a new order of magnification with the electron microscope, but the secret of their mechano-electric transducing or amplifying action is not revealed by it The innervation of the hair cells is a complicated network, with contacts of many cells to a fiber and several fibers to a cell More recently the efferent character of the bundle of Rasmussen has become clear, and Dr Galambos will tell you how it modifies the sensitivity of the auditory receptors Here, in a feed-back control from the central nervous system, is a really new principle of cochlear action

Enough of generalities and previews Let us look rapidly

Thanks to the monumental work of Prof Georg von Békesy, who should be telling you in person his half of this story, we know quite definitely the gross pattern of movement of the cochlear partition This is the now-famous traveling wave pattern, which many of you saw illustrated in Prof Bekesy's motion picture Equally well established is the proposition that the extent of the traveling wave pattern along the cochlear partition, and the position of its maximum of displacement both vary with the frequency of the sound waves Thus the cochlea does act as an acoustic analyzer The apical end of the cochlear partition is moved and its sensory nerves are stimulated only by low frequency sounds, and those at the basal end near the round window are stimulated by all sounds (of moderate strength) whether low, medium or high in frequency This is not the exclusive one-frequency-to-one-place pattern of the piano keyboard, but it is a definite *place principle* of cochlear action, and it is not a matter of speculation but of observation Békésy has seen it hundreds of times in actual cochleas and in models, and we have verified it time and again with our electrical recordings

At the same time the cochlea also operates, within limits, on the telephone or frequency principle Nerve impulses tend to group in successive volleys that reproduce the frequency of the stimulating sound waves Up to the natural limit set by the refractory period of the nerve fibers, by the variability of their latency of discharge, and by the temporal dispersion introduced by the traveling wave pattern of cochlear action, the nerve impulses carry information about frequency *directly*, according to the frequency principle Wever postulated his volley principle of firing-in-turn as an accessory to the basic frequency principle, and was proved right experimentally by Galambos and again by Tasaki They will give you some of their details of the story later

I have alluded above to a major principle of nervous transmission namely, the *nerve impulses are all-or-none* Another is that *in the nerve axons they travel in insulated channels* They are triggered by the stimulus, but their energy is provided by the fibers Their maximum sustained frequency is two to three hundred impulses per second in a brane As a result of this variation, the stiffness ("volume elasticity") of the cochlear partition varies by a factor of at least 100 from one end to the other

The cochlear partition has significant stiffness and also mass Contrary to earlier opinions, it is not under tension When cut, the edges do not retract The movements of the partition, like those of the middle ear, are quite heavily, but not critically, damped Because of the gradation in stiffness and mass, different parts of the basilar membrane have different resonant frequencies, but the various parts cannot move as independent resonators The basilar membrane, and the organ of Corti on it, are continuous structures Their elements are coupled to one another elastically and also by friction The endolymph and the perilymph provide some of the friction

## TRAVELING WAVE PATTERN OF THE COCHLEAR PARTITION

An increase of pressure on the footplate of the stapes, caused by a sound wave, causes a wave of acoustic pressure to spread through the fluid in the cochlea with approximately the speed of acoustic transmission in water, about 1500 m/sec Because of the small size of the cochlea, the increase in pressure is virtually simultaneous throughout The only elastic portion of the walls of the bony labyrinth is the round window, and its membrane bulges outward and allows inward movement of the stapes Fluid moves from oval window toward round window The cochlear partition lies in the path of this movement, and it bulges toward the round window If the movement is very slow, there will also be some flow through the helicotrema, but all parts of the cochlear partition do not move with equal promptness The relatively stiff portion in the basal turn moves very nearly in phase with the driving force, but the more flexible apical portions, particularly those whose resonant frequency is lower than the frequency of the acoustic wave that is driving the partition, tend to lag behind As the acoustic wave reverses its pressure, the portion that is "tuned" to lower frequencies tends to overshoot and continues to lag behind the driving force exerted on it by the acoustic pressure in the fluid Thus, because of

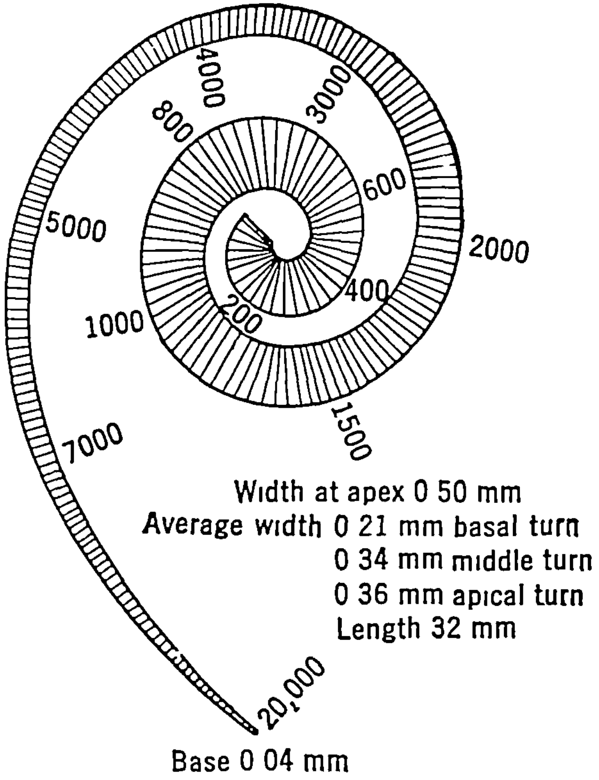


Fig 1 Diagram of the human basilar membrane showing the approximate location of the regions of maximum amplitude of movement for tones of different frequency The width of the membrane is exaggerated relative to its length in order to show the widening more clearly (Stuhlman)

at some of the details We are all audiologists, so I shall not take time to review the familiar basic anatomy of the cochlea, but in Dr Békésy's absence I shall recall briefly the story of the traveling waves, and then pass on to some of the finer details

## MECHANICAL PROPERTIES OF INNER EAR STRUCTURES

In the inner ear the basilar membrane widens gradually from 0 04 mm at the stapes to 0 5 mm at the helicotrema Certain other measurements, such as cross section of the cochlear canal and relative sizes of certain types of cell in the organ of Corti, are also graded from end to end, but the important variation that allows the cochlea to act as a mechanical acoustic analyzer is in the width of the basilar meming wave moves on toward the apex. The velocity of travel, therefore, diminishes, and consequently the wave length of the displacement pattern becomes shorter. A little distance beyond the position of maximum amplitude there is no significant movement at all. In the region of rapid diminution of amplitude the phase lag amounts to a full cycle or more.

If the driving frequency is increased, the position of maximum amplitude moves toward the oval window; if it is decreased the maximum moves toward the apex (see Fig. 5). At about 100 c.p.s. it is very close to the helicotrema. At 2000 c.p.s. there is very little movement beyond the mid point of the cochlear partition, but the extreme basal end of the partition moves in response to *all* frequencies within the audible range.

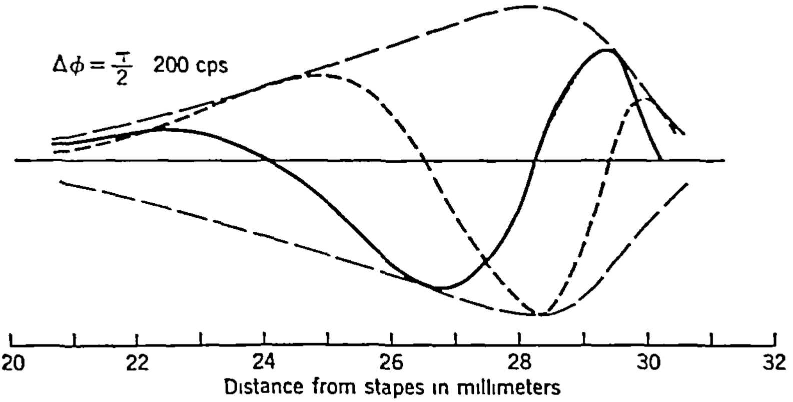


Fig. 4. Two displacement patterns are shown at an interval of a quarter of a cycle. The dashed line is the envelope of the instantaneous patterns and corresponds to the dashed curve in Fig. 5 upper (Békésy.)

The unsymmetrical traveling wave pattern of movement, with its rather flat maximum of amplitude and its abrupt apical reduction in activity, has been shown to be a necessary and predictable consequence of the principles of acoustic resonance in a system such as the cochlea with gradation of stiffness, mass, damping and coupling. The traveling wave pattern has been reproduced in appropriate physical models, and it has been observed directly in the cochlea under the

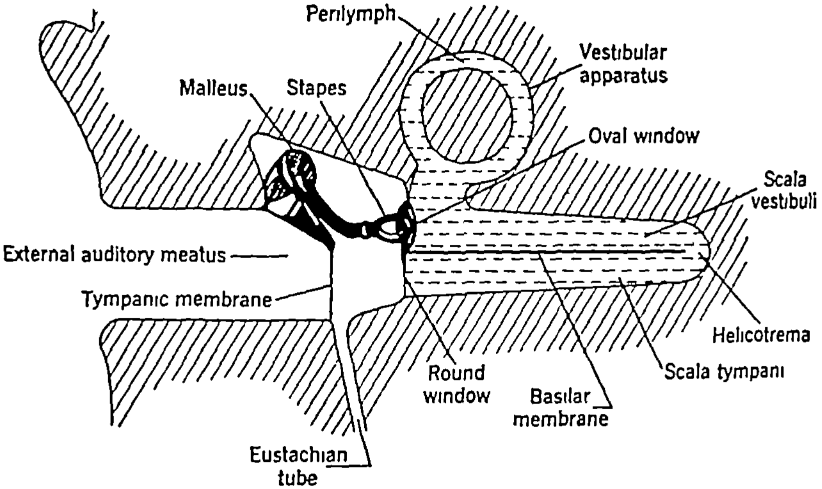


Fig 2 Overall diagram of the ear showing the ossicles in the middle ear (the incus is not labeled) and the fluid-filled inner ear The cochlea is drawn as a short straight chamber instead of a long coiled canal (Bekesy)

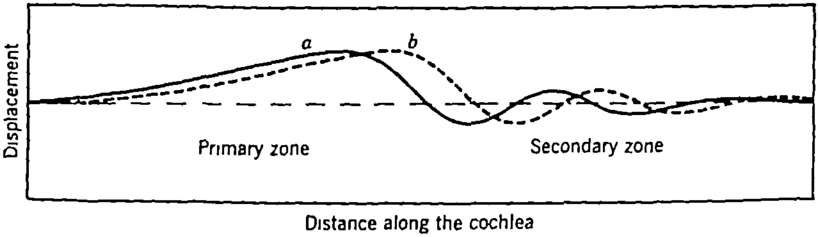


Fig 3 The solid line (a) shows the displacement pattern of the cochlear partition at one instant and the broken line (b) the pattern an instant later Actually the waves die out quite rapidly in the secondary zone and their wave length becomes progressively shorter and shorter (Wever Lawrence and Bekesy)

the gradation of stiffness, a *traveling wave* of displacement appears on the cochlear partition (see Fig 3), furthermore, because of the continuity of the partition, the stiffer portion, moving almost as a unit, drives the more flexible portion

The traveling wave increases in amplitude as it moves apically and reaches its maximum near the region where resonant frequency of the basilar membrane corresponds to the frequency of the driving waves (see Fig 4) The amplitude of movements falls off rather rapidly beyond this point The phase lag increases more and more rapidly as the travel-of a system of diagonal fibers, and also a jelly-like substance It yields to slow movements but is quite stiff and resistant to quick movements It returns rather slowly after being detached from its normal attachment to the organ of Corti and then displaced

Apparently, as the basilar membrane bulges "upward" or "downward" (see Fig 7), the stiff reticular lamina tends to

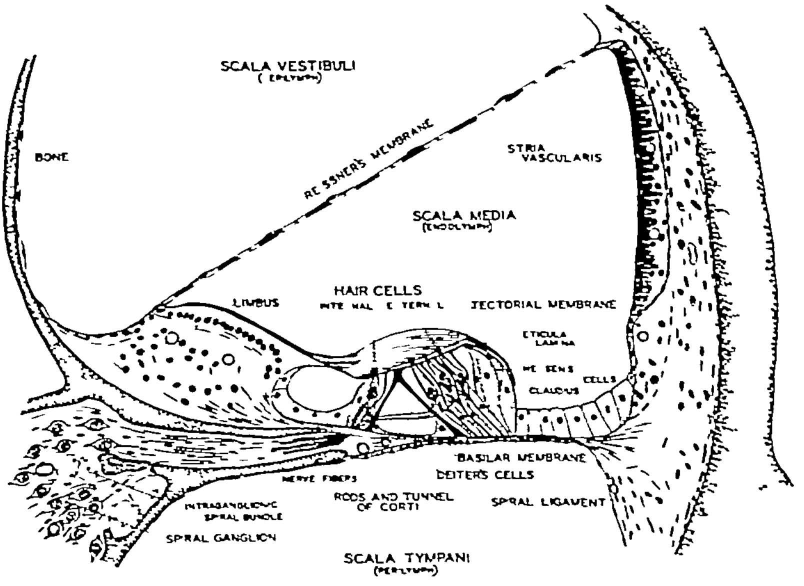


Fig 6 Camera lucida drawing of a cross section of the cochlear partition in the second turn of a guinea pig cochlea The attachment shown here of the tectorial membrane to the inner supporting cell and to Hensen's cells is based on microdissection of fresh unfixed specimens

rock, on the support of the rods of Corti, around an axis at the attachment of the basilar membrane to the bony modiolus The tectorial membrane swings on its attachment to the limbus The result is a shearing action between the tectorial membrane and the reticular lamina (see Fig 8) The "hairs" arise from the cuticular plates of the hair cells, which are set firmly in the reticular lamina, and their outer ends are firmly imbedded in the tectorial membrane, therefore, as the basilar membrane bulges, the hairs are bent The force of the move-microscope with stroboscopic illumination It allows the cochlea to act as a mechanical frequency analyzer, because the extent of activity and position of maxima vary as functions of frequency It introduces additional features, such as asymmetry, progressive time and phase lag, and significant longitudinal as well as transverse bending of the cochlear partition, that contribute to the pattern of neural excitation that results from the movements of the partition

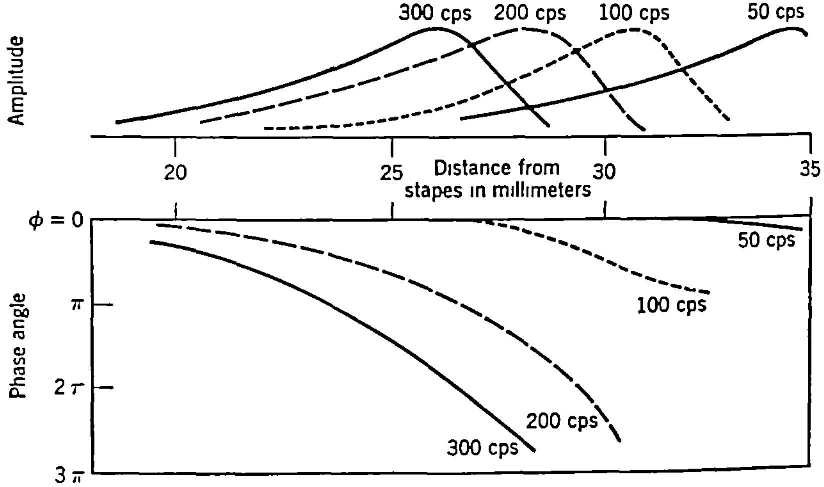


Fig 5 The upper set of curves shows the amplitude of displacement of the cochlear partition at various distances from the stapes and for several driving frequencies The lower set of curves shows the corresponding phase angles (Bekesy)

## THE FINE MOVEMENTS OF THE ORGAN OF CORTI

The fine movements of the organ of Corti and the tectorial membrane have been observed under the microscope by stroboscopic illumination and described in some detail by Békésy In any one segment the basilar membrane, organ of Corti, tectorial membrane, and usually Reissner's membrane also, move in phase with one another The basilar membrane is fibrous and elastic, and basically it determines the traveling wave pattern of vibration described above The cells of Hensen form a soft cushion supporting the stiffer plate of the reticular lamina The tectorial membrane is hinged like the cover of a book along the edge of the limbus It is composed and the hairs are presumably bent longitudinally instead of radially (see Fig 9)

The exact significance of these different directions of movement in relation to the excitation of nerve impulses by the hair cells is still a matter of speculation, but the bending of the hairs is the final and critical mechanical event that has been recognized in the mechanism of stimulation At this point the significant events apparently become electrical, for this bending of the hairs seems to release energy in the form of bioelectric potentials, and these potentials are in all probability an important intermediate step in the mechanism of excitation of the auditory nerve fibers

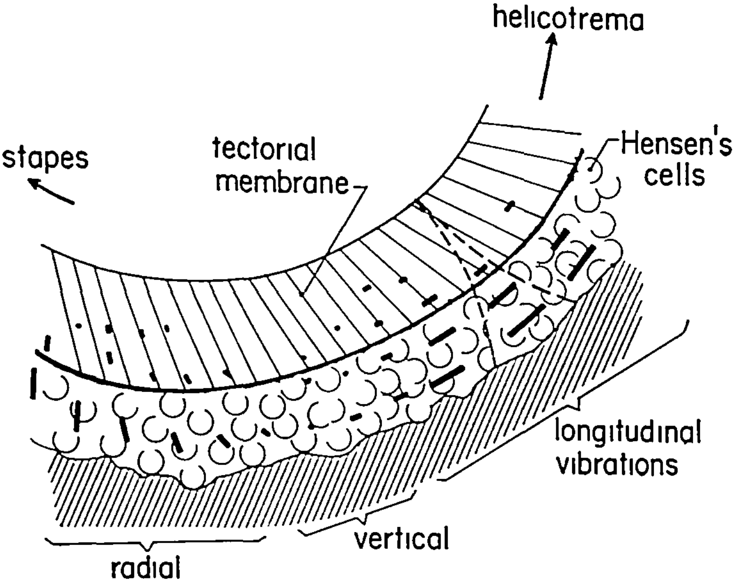


Fig 9 Movements in the cochlear partition viewed from the upper edge of the stria vascularis The greatest amplitude of displacement in the pattern shown in Fig 6 is in the region here labeled vertical (Bekesy)

The *endolymph,* which fills scala media, differs sharply from perilymph in its ionic content Unlike all other body fluids, it is high in potassium and low in sodium It more nearly resembles intra-cellular fluid in this respect Typical

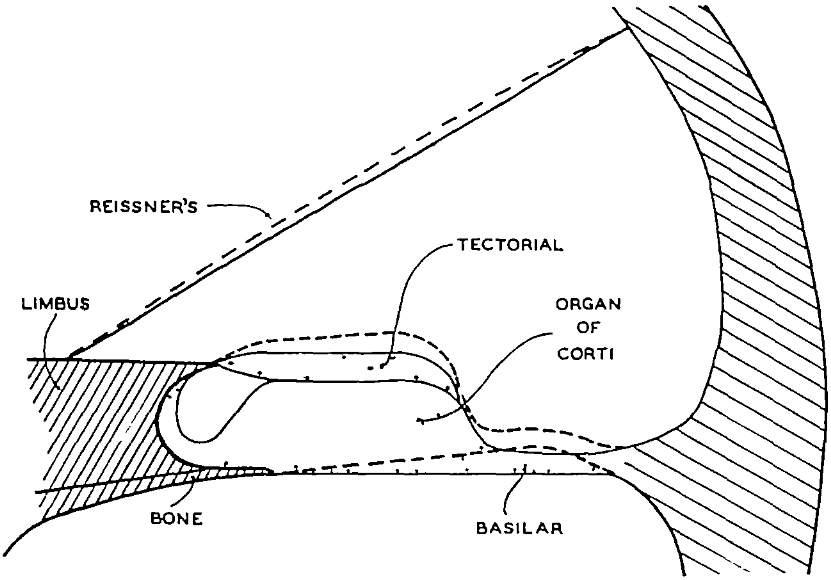


Fig 7 Probable pattern of displacement of the cochlear partition seen in cross section

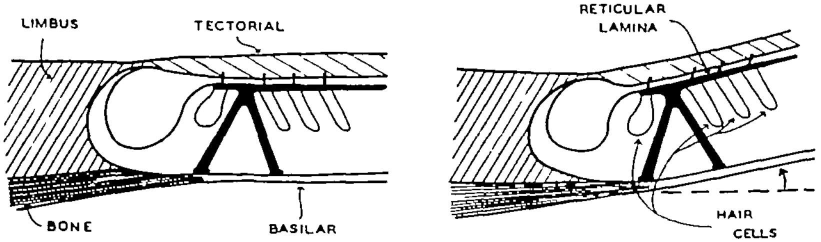


Fig 8 Probable pattern of shearing action between tectorial membrane and reticular lamina with bending of the hairs

ments of the cochlear partition is rather efficiently concentrated on the shearing action

The movement described above is associated with an approximately *radial* displacement of Hensen's cells, as seen under the microscope, and a corresponding radial or slightly diagonal bending of the hairs This movement is characteristic on the basal side of the position of maximal amplitude On the apical side, however, due to the shorter wave length of the traveling wave and sharper longitudinal bending of the basilar membrane, a *longitudinal* movement predominates,

## THE ENDOCOCHLEAR POTENTIAL

The interior of scala media, the endolymph, is electrically *positive* relative to the perilymph in scala vestibuli and scala tympani and to the spiral ligament and extra-cochlear tissues in general This potential is +80 mv It is encountered abruptly at the point where the exploring electrode enters the endolymphatic space The change of potential in going from the interior of a hair cell through its cuticular layer into scala media is thus about 150 mv

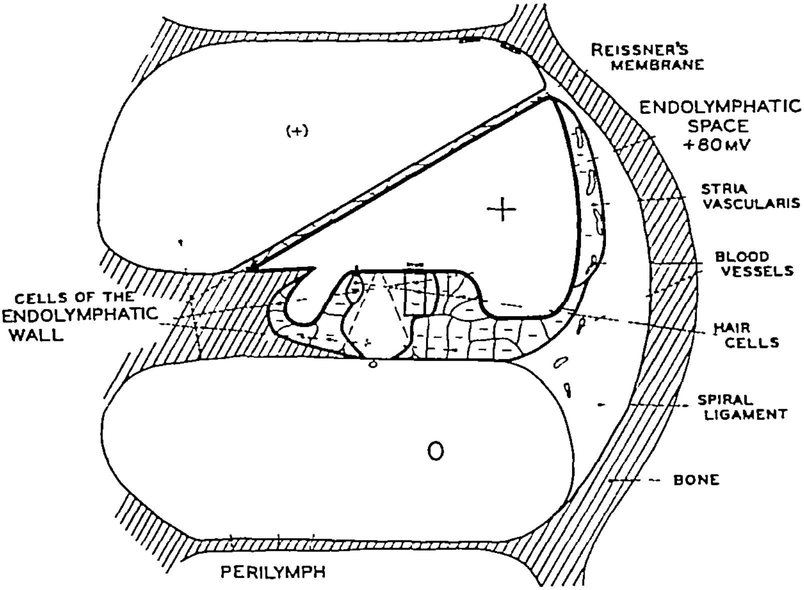


Fig 11 The endolymphatic space bounded by the heavy line carries a positive electrical charge of 80 mv relative to the perilymph in scala tympani Scala vestibuli is not more than 5 mv positive The interiors of all of the cells of the cochlear partition are electrically negative

The endocochlear potential is closely dependent on an adequate oxygen supply It falls, reversibly, to a very low level at the stage of asphyxia that is reached in extreme Cheyne-Stokes respiration (in anesthetized, moribund guinea pigs) Full recovery requires only a few seconds after a large single gasping inspiration It is also abolished rapidly by injection of cyanide or azide into scala tympani or scala media It is analyses of endolymph, perilymph and cerebro-spinal fluid are given in Fig 10 The endolymph has sometimes been described as "viscous," but this is probably true only for certain fish and perhaps other lower forms

The endolymph is probably secreted by the stria vascularis Whether it is also reabsorbed wholly or only in part by the same structure is a matter of debate

|  | Spinal Fluid | Perilymph | Endolymph |
|---|---|---|---|
|  | millieqivalents per liter |  |  |
| Potassium | 4 2 | 4 8 | 144 4 |
| Sodium | 152 0 | 150 3 | 15 8 |
| Chloride | 122 4 | 121 5 | 107 1 |
|  | milligrams per cent |  |  |
| Protein | 21 0 | 50 0 | 15 0 |

Fig 10

## INTRACELLULAR POTENTIALS

Nearly all cells show a negative intracellular potential Explorations of the cochlea and the auditory nerve with very fine microelectrodes reveal these intracellular potentials, ranging from –60 or even –80 mv relative to the potential of the perilymph in large cells, such as Hensen's or Claudius' down to –20 mv or so in the cells of Reissner's membrane The exact value seems to be a function of the amount of injury caused by the microelectrode, the greater the injury the lower the value The hair cells, like the nerve fibers and supporting cells, are electrically *negative* internally signal, but to a root-mean-square value, integrated over a very short time Thus the summating potentials reproduce approximately the form of the *envelope* of the original acoustic signal The positive and the negative summating potentials are opposite in sign They can be separated by the greater vulnerability of the positive summating potential to oxygen lack and other injury, and by the more apical site of generation of the negative response The input-output relations of the summating potentials are now being investigated They are not simple

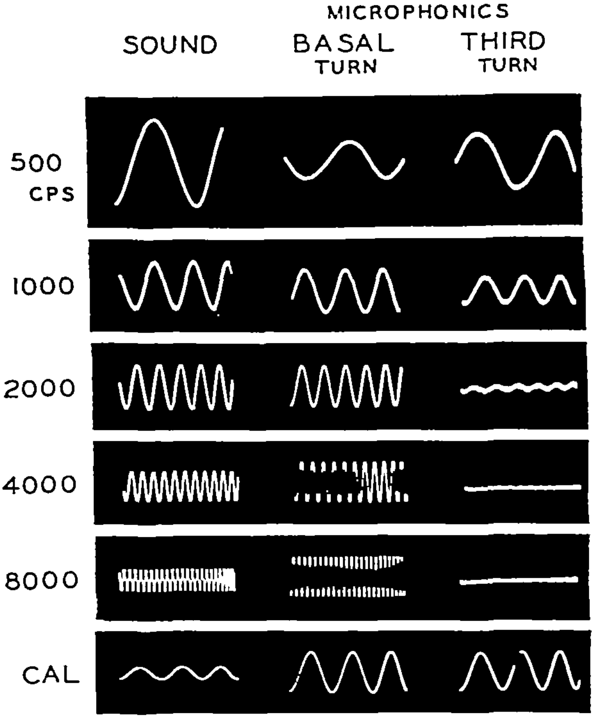


Fig 12 The cochlear microphonic recorded by intracochlear electrodes on opposite sides of the cochlear partition reproduces the sine wave form of a pure tone The basal turn responds to all frequencies but the third turn responds only to frequencies below about 3000 c.p s

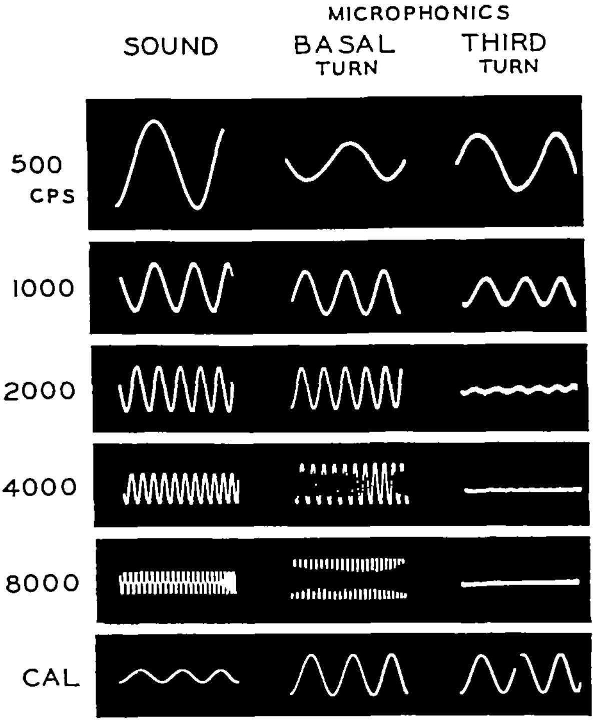
The cochlear microphonic is generated at the cuticular surface of the hair cells This is clearly proved by exploration not immediately affected by injection of isotonic potassium chloride, choline chloride, or potassium glutamate into scala tympani or scala vestibuli It does fail, although less rapidly than with cyanide, following surgical injury to scala media or the injection into scala media of a solution that differs substantially in ionic content from the analytic figures for endolymph given in Fig 10

The endocochlear potential is modified by displacement of structures within the cochlear partition Displacement of the basilar membrane toward scala tympani, as by injection of fluid into scala media or an inward movement of the stapes, causes an increase in the positive potential by as much as 5 or 10 mv Movement in the opposite direction, as by outward movement of the stapes, causes even greater reductions in the potential Movements of Reissner's membrane alone are not effective, but movements of tectorial membrane relative to the reticular lamina, when it is manipulated by a microneedle, produce just such changes in potential The changes are related to displacement, not to velocity, and are sustained as long as the displacement is maintained

The *source* of the endocochlear potential has not been identified, although both hair cells and the stria vascularis have been suggested The *changes* in endocochlear potential, described above, are clearly associated with the organ of Corti, almost surely the hair cells, but it is not certain that the resting positive endocochlear potential is generated here Perhaps a separate electric response to mechanical stimulation occurs in the hair cells and simply adds to the background potential that is produced by another "generator"

## THE COCHLEAR MICROPHONIC AND THE SUMMATING POTENTIALS

The cochlear microphonic and two summating potentials (positive and negative) are all electric responses to acoustic stimulation The cochlear microphonic is linearly proportional, up to a limit, to the displacement of the cochlear partition and thus, indirectly, to the instantaneous acoustic pressure The microphonic thus reproduces the *wave form* of the acoustic stimulus (see Fig 12) The summating potentials are proportional, not to any instantaneous value of the acoustic signal, but to a root-mean-square value, integrated over a very short time Thus the summating potentials reproduce approximately the form of the *envelope* of the original acoustic signal The positive and the negative summating potentials are opposite in sign They can be separated by the greater vulnerability of the positive summating potential to oxygen lack and other injury, and by the more apical site of generation of the negative response The input-output relations of the summating potentials are now being investigated They are not simple



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The cochlear microphonic is generated at the cuticular surface of the hair cells This is clearly proved by exploration with microelectrodes The microphonic, and in all probability the summating potentials also, seem to reflect the bending of hairs in the appropriate direction Apparently at intensities high enough to evoke the summating potentials, some kind of mechanical rectifying or detector action takes place in the inner ear to cause an unsymmetrical, persistent one-way bend in the hairs of certain cells In some cases the bending is probably across, in others lengthwise of the organ of Corti (A theory that includes this and several other aspects of the electrophysiology of the cochlea has recently been published in *Physiological Reviews,* 1957 )

Both the cochlear microphonic and the summating potentials are continuously graded responses, linearly related within limits, to the intensity of the acoustic stimulus, and with no true "threshold" like that of all-or-none action potentials No evidence of any all-or-none response in the sensory cells or of a refractory period has been found, even when the cochlear microphonic was recorded from an electrode inside a hair cell Both the microphonic and the summating potentials show very little or no fatigue or adaptation

The cochlear microphonic "appears," in the sense that it reaches an rms value of a microvolt or thereabouts, at a much lower sound pressure level than the summating potential, except at the extreme high-frequency limit of response In the basal turn in the guinea pig the increase is linear, with the sound pressure level up to about 80 db relative to 0 0002 microbar The response then increases more slowly and usually goes through a maximum At low frequencies ordinary mechanical non-linear distortion limits the output At higher frequencies the electrical output is limited, but the wave form of the cochlear microphonic is well maintained, with little or no "peak-clipping," in contrast to the flat-topped waves seen at lower frequencies The summating potentials "appear" some 20 db above the cochlear microphonic, and continue to increase up to limits set only by acoustic trauma to the organ of Corti

The cochlear microphonic, like the endocochlear potential, is closely dependent on an adequate oxygen supply Later we shall hear evidence that the cochlear microphonic is not entirely dependent on the positive potential of the endolymph The cochlear microphonic, however, apparently does represent, as Békesy originally implied, an amplifier action in which the acoustic stimulus "valves" the energy from a preexisting "biological pool," such as the endocochlear potential

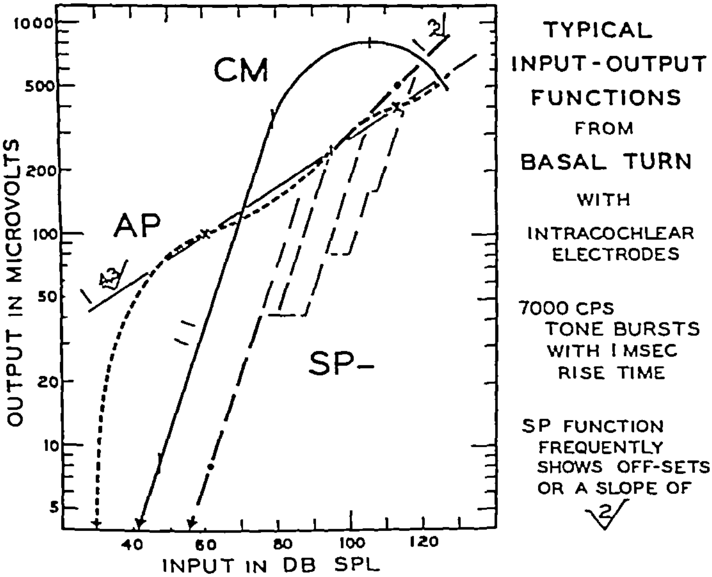

Fig 13 The voltage of the cochlear microphonic is proportional to the sound pressure level up to about 80 db SPL but goes through a maximum at about 105 db SPL The height of the action potential spike ($N_1$) increases rapidly from threshold and then gradually at a rate that varies between the third and the fifth root of the sound pressure level The negative summating potential is directly proportional to sound pressure level when it first appears It does not show a maximum like CM, but its increase is often interrupted by plateaus No single typical curve can yet be drawn for SP

We may add that the negative intracellular polarization is also such a "pool" In any case it now seems clear that the sustained changes in the endocochlear potential noted above certainly represent a modulation of a biological source of energy, and not simply a passive physical transducer mechanism

The summating potential, as usually seen, is a displacement of the baseline of the oscilloscopic record on which the cochlear with microelectrodes The microphonic, and in all probability the summating potentials also, seem to reflect the bending of hairs in the appropriate direction Apparently at intensities high enough to evoke the summating potentials, some kind of mechanical rectifying or detector action takes place in the inner ear to cause an unsymmetrical, persistent one-way bend in the hairs of certain cells In some cases the bending is probably across, in others lengthwise of the organ of Corti (A theory that includes this and several other aspects of the electrophysiology of the cochlea has recently been published in *Physiological Reviews*, 1957 )

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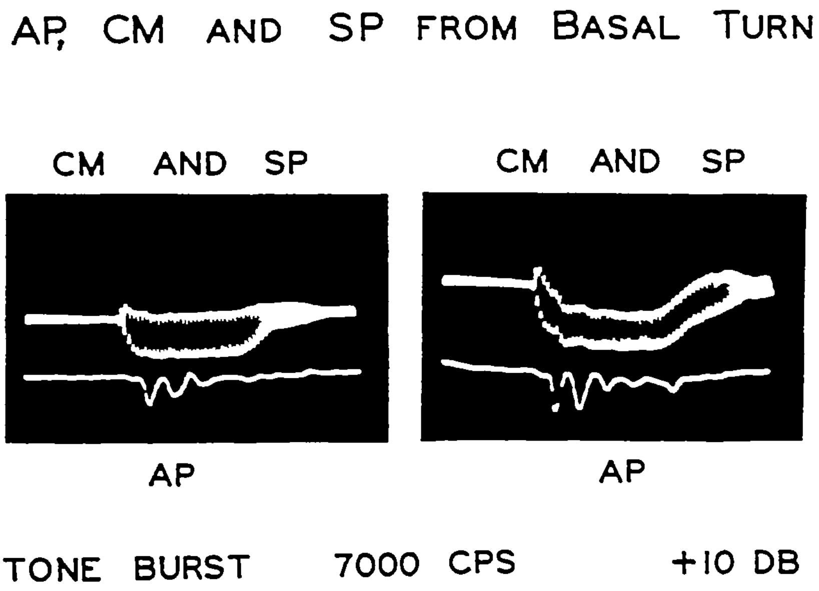

Fig 15 The AP response can be separated from CM and SP by using intracochlear electrodes an appropriate input network and two recording channels The stimulus for the responses at the right was 10 db stronger than for those on the left Note that AP and SP- have increased while CM has decreased slightly

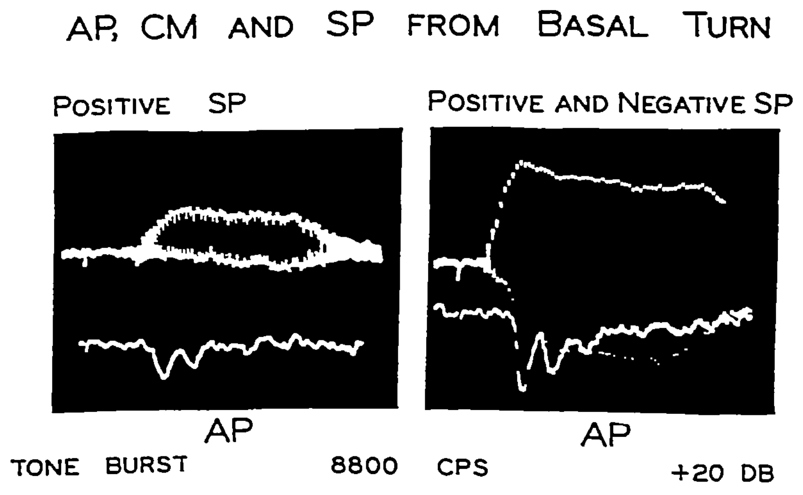

Fig 16 In some preparations with weak stimuli the SP response is dominantly positive A stronger stimulus gives a composite SP response.

microphonic is superimposed It is a paradoxical fact that, with mild anoxia, abnormal ionic concentrations, etc, while the cochlear microphonic diminishes the negative summating potential increases The diphasic effect of anoxia, etc, is best explained by assuming that, *1* there is a positive as well as a negative summating potential, generated by a different set of sensory cells, and that *2* the positive response is more sensitive to anoxia than the negative The negative summating potential seems to be stronger, although higher in threshold, and only under more severe anoxia or ionic injury does it in its turn weaken and finally disappear

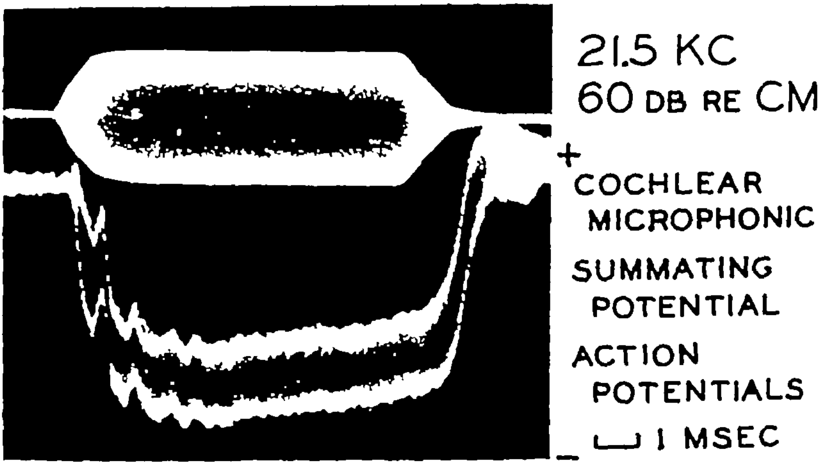

Fig 14 The upper trace is the electrical pattern of a tone burst at 21 5 kc An electrode on the round window of guinea pig records a complex electrical response consisting of cochlear microphonic (at the frequency of the sound waves) summating potential (downward displacement of the base line) and action potentials (the peaks and notches on the descending limb of the SP response) The stimulus is maximal for CM. Its sound pressure level is 60 db above the level needed for a CM response of 3 $\mu v$ The apparent decay of SP during the tone burst is an artifact due to the condenser coupling of the recording amplifier After the end of the tone burst the CM response to the reverberation continues to be nearly maximal

We shall rely on Drs Galambos and Tasaki to provide further details concerning the nerve action potentials in the second order and first order auditory neurons respectively Let us devote the remaining moments to a quick interpretive summary of some of our statements about cochlear mechanics, is strongest on the apical side of the position of maximum excursion The sustained bend of the hairs presumably acts as a steady stimulus to the hair cells that are affected, but compared to the alternating shearing movements revealed by the cochlear microphonic this mechanism is relatively insensitive The rectifying action, as revealed by the negative summating potential, continues to increase, however, after the vibratory movements, and with them the cochlear microphonic, have reached their maximum The rectifying action, however it is produced, seems to be a mechanism that significantly extends the dynamic range of the ear

The complete theory, as presented elsewhere, considers the mechanism of limitation of crosswise bending (and with it the cochlear microphonic) in more detail and it also includes a second rectifying action, associated with the crosswise bending, that depends on the viscous properties of the tectorial membrane This second mechanical rectifying action and consequent one-way bias of the hairs is invoked as the basis of the positive summating potential, but this extension of the theory, as well as a possible inhibitory action of the positive summating potential, is admittedly more speculative than the postulate of the longitudinal "shift" and its production of the negative summating potential

The association of the cochlear microphonic with the bending of the hairs seems very well established The mechanism that connects the two is completely obscure, however A vague suggestion that the mechanical distortion changes the electrical resistance of the upper ends of the hair cells has been offered but without supporting evidence Whatever the mechanism, the bending of the hairs is supposed to account for not only the cochlear microphonic but also both of the summating potentials, but these three electrical responses, it should be noted, are observed phenomena, not theories

Consideration of the extreme sensitivity of the ear, and also the fact that a potential change persists indefinitely if a static displacement of tectorial membrane relative to the reticular lamina is maintained mechanically, leads to the conclusion already stated that *the energy of the electrical re-*

and to the relations between movement and potential, and between potential and nerve impulses

We conceive that, as the basilar membrane, and the organ of Corti with it, bulge one way or the other, there is a shearing action between the stiff reticular lamina of the organ of Corti and the stiff but viscous tectorial membrane that lies in contact with it, because the tectorial membrane pivots around a different axis, as illustrated in Fig 7 The shearing action bends the hairs of the hair cells, which are attached both to the organ of Corti and to the tectorial membrane This bending is the mechanical movement that is critical for stimulation Protection against too great bending is probably provided by the attachment of the tectorial membrane directly to the outer and inner borders of the organ of Corti

The longitudinal bending causes longitudinal vibratory movements among the cells of the organ of Corti, and presumably bends the hairs lengthwise of the cochlear partition The longitudinal bending is sharpest in the "cut-off" region on the apical side of the maximum and is probably negligible on the basal side It is uncertain as yet whether the external and the internal hair cells are equally sensitive to radial and to longitudinal bending of their hairs Probably they differ, and the differential stimulation of the two sets by the different directions of bending allows possibilities, through inhibitory neural interactions within the central nervous system, of sharpening the "place" aspect of frequency discrimination

The traveling waves are known to produce eddies in the cochlear fluids on the apical side of the position of maximal amplitude The forces that produce eddies, we believe, also tend to cause an unsymmetrical longitudinal shift or "creep" to the tectorial membrane relative to the organ of Corti Such a shift would cause a one-way longitudinal bending of the hairs This would be a mechanical rectifying action It allows the cochlea to "detect" efficiently and respond with nerve impulses to high-frequency acoustic signals above 2000 per second Just as the cochlear microphonic is the electrical sign of a symmetrical vibratory bending of the hairs, we believe the negative summating potential is the electrical sign of an unsymmetrical, rectified longitudinal shift This shift medullated dendritic branches of the primary neurons in the organ of Corti

At frequencies below about 300 c p s each sound wave acts like an individual stimulus to the nerve fibers Excitation apparently occurs during the "falling phase" of the cochlear microphonic, *i e* while scala media (and vestibuli) is becoming more negative relative to scala tympani This corresponds to the phase of *outward* movement of the stapes The phase relation of neural excitation to the cochlear microphonic is correct for the electrical theory, although this may not be immediately obvious The current flows from hair cell into nerve fiber and outward across the nerve membrane, and thus can excite the non-medullated dendritic terminals like one tremendous node of Ranvier, or like non-medullated fibers elsewhere Spatial summation between the several hair cells attached to a given nerve fiber is clearly positive, and also a facilitating action between summating potential and cochlear microphonic

This is at least a reasonable working hypothesis or "model" of the action of the cochlea as a sense organ

## ACKNOWLEDGEMENTS

A more complete discussion of much of the material in this article, and a full list of references will be found in DAVIS, H "Biophysics and Physiology of the Inner Ear" *Physiol Rev*, 37 1-49, 1957

Some pertinent additional material appears in another paper entitled "Modification of Cochlear Potentials Produced by Streptomycin Poisoning and by Extensive Venous Obstruction," by the present author and his associates, in this volume

Several sections of this paper are taken almost verbatim from the chapter prepared by the present author for the forthcoming "Handbook of Physiology" of the American Physiological Society

The courtesy of the following authors, journals and publishers in allowing reproduction of figures or data is gratefully acknowledged

*sponses is derived from the metabolism of the tissues, not from the acoustic stimulus* The latter serves merely to "valve" the flow of energy from the biological source The result is an amplifier action in the sense organ prior to stimulation of the nerve fibers

The cochlear microphonic and the negative summating potential are believed to excite directly the nerve fibers in contact with the hair cells Only a passive role as electrical conductors is ascribed to the nerve endings No latency can be seen between mechanical displacement of the cochlear partition and the cochlear microphonic It is not yet clear whether there is synapse-like delay in excitation or whether the observed latency of action potentials (in the modiolus) should be attributed chiefly to conduction time in the non-

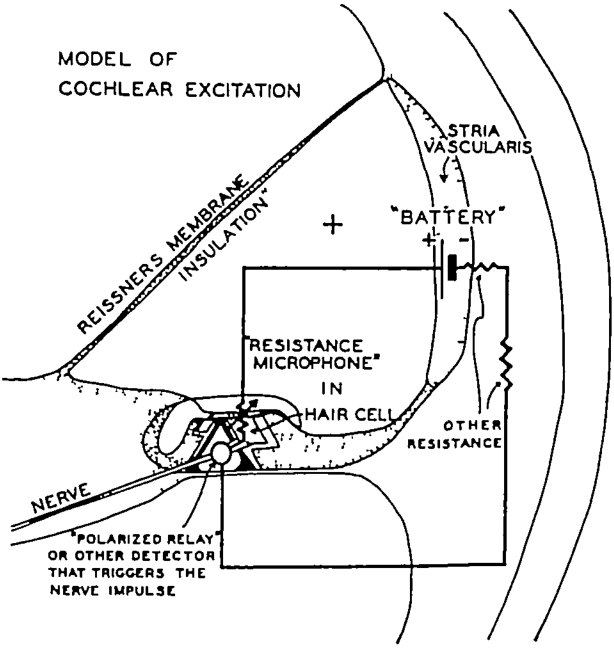

Fig 17 An electrical model of excitation of nerve impulses in the cochlea Additional batteries not shown in the diagram are located at the cell membranes of the hair cells and of the nerve endings The return circuit from nerve ending to the stria vascularis is not restricted to the narrow anatomical path indicated in the diagram but is diffuse through all intervening tissues except the scala media

greedy, he would ask for more direct observational data on the phase response of the cochlear partition, particularly at frequencies above 500 c p s , but to have the picture we have of the mechanical analysis is so good that we should not be very greedy Taking advantage of the established reasonableness of the assumption of linear superposition, one can, at least in principle, determine rather approximately, as a function of time, the pattern of displacement of the cochlear partition in response to any specified acoustic stimulus, sinusoidal or complex, periodic or aperiodic

My second comment has to do with two different theoretical points of view from which we can examine the next stage of the auditory process By the next stage, I mean the transduction from mechanical displacement of the cochlear partition to excitation of the neurons of the auditory nerve The first point of view is that of the audiologist, or the experimental psychologist, who wants to understand the overall behavior of the individual The other point of view is that of the physiologist who wants to know exactly what does what

A few years ago, we had only a very tentative picture of this second stage of the auditory process The displacement of the cochlear partition squeezed the hair cells, the hair cells shocked the nerve fibers, and impulses went up the VIIIth nerve Today, however, the mechano-neural transformation is the focus of research attention Does it play a role in the sharpening of the mechanical frequency analysis? To what extent are its parameters under the control of higher centers? Does the band width of the "cochlear filter" vary with the alertness of the organism, with the listeners' set, with the task assigned?

It is evident from Dr Davis' summary that those questions do not yet have positive answers, but equally evident that answers are at least on the way

The primary concern of many of the researchers who are hard at work on the mechano-neural transformation is an understanding of the physiology of the process What structures respond in what manner under what conditions? The main interest of many audiologists and psychologists, on the

Fig 1 STUHLMAN, O, JR "An Introduction to Biophysics" John Wiley & Sons, 1943

Fig 2, 4, 5 VON BÉKÉSY, G "Handbook of Experimental Psychology" John Wiley & Sons, 1951

Fig 3 WEVER, E G, LAWRENCE, M, and VON BÉKÉSY, G *Proc Natl Acad Sci U S*, 40 508, 1954

Fig 6 DAVIS, H *Jour Acoust Soc Amer*, 25 1180 1953

Fig 7, 8, 17 DAVIS, H "Physiological Triggers" American Physiological Society, 1956

Fig 9 VON BÉKÉSY, G *Jour Acoust Soc Amer*, 25 786, 1953

Fig 10 Data from SMITH, C A, LOWRY, O H, and WU, M L THE LARYNGOSCOPE, 64 141, 1954

Fig 11 TASAKI, I, DAVIS, H, and ELDREDGE, D H *Jour Acoust Soc Amer*, 26 765 1954

Fig 14 PESTALOZZA, G and DAVIS, H *Amer Jour Physiol*, 185 595 1956

# TRANSMISSION AND TRANSDUCTION IN THE COCHLEA

## Theoretical Discussion of Hallowell Davis' Paper

J C R LICKLIDER,*

Bolt Beranek and Newman Inc

Cambridge, Mass

My first comment on Dr Davis' masterful job concerns the theoretical significance of Professor Békésy's experimental contributions on the one hand, they displaced the speculations, most of which had been pretty far afield, about cochlear mechanics, and they sent the speculators scurrying up the auditory system to happier hunting grounds, on the other hand, they set the stage for a series of mathematical theories, not theories so much as assimilations, that reduced to formulas the essential schema of the cochlear mechanical frequency analysis

It is probably impossible to overstate the importance, to the rest of auditory theory, of having this solid foundation on which to build If one could ask for more without being greedy, he would ask for more direct observational data on the phase response of the cochlear partition, particularly at frequencies above 500 c p s , but to have the picture we have of the mechanical analysis is so good that we should not be very greedy Taking advantage of the established reasonableness of the assumption of linear superposition, one can, at least in principle, determine rather approximately, as a function of time, the pattern of displacement of the cochlear partition in response to any specified acoustic stimulus, sinusoidal or complex, periodic or aperiodic

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*Formerly at Massachusettes Institute of Technology

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It is evident from Dr Davis' summary that those questions do not yet have positive answers, but equally evident that answers are at least on the way

The primary concern of many of the researchers who are hard at work on the mechano-neural transformation is an understanding of the physiology of the process What structures respond in what manner under what conditions? The main interest of many audiologists and psychologists, on the other hand, is an understanding of the form of the transformation They are less interested in knowing what structures mediate it than they are in knowing the shape of the "transfer characteristic" Their hope, of course, is to apply the mechano-neural transformation to the signal that results from the mechanical cochlear analysis of the acoustic stimulus That would carry the quantitative description of the process through another stage and give us a picture of the incoming signal as seen by the nervous system

It seems to me worthwhile to distinguish between the advances in the two areas that correspond to the interests of the physiologist, on the one hand, and the audiologist or psychologist, on the other Let us consider them in reverse order

Insofar as the form of the transduction is concerned, the major advance, in what Dr Davis has described, is the demonstration that the cochlear microphonic potential is supplemented by the summating potential The microphonic normally is dominant at low frequencies and low intensities, the summating potential at high frequencies and high intensities The summating potential appears as though it were derived through rectification and smoothing of the microphonic potential, and those two operations give us a rough picture of *the form of the process From the recent developments,* we begin to see how the auditory system gets its extreme dynamic range We see also that its behavior in response to strong signals is fundamentally different from its behavior in response to weak signals

On the physiological side, the fundamental advance was the understanding that the cochlear potentials are energy-release phenomena and not direct-energy-transduction phenomena Relating the physiology to the anatomy, there is the clear evidence that the focal point of the process is the hair cell

When it comes down to the details of the process, however, the picture is extremely complicated There are actually seven potentials to be considered, and there are at least seven structures that are regarded by one investigator or another as playing important roles The opportunities for theory construction, here, are, therefore, obviously quite as good as they ever were in the study of the mechanical action of the cochlea. I think that Dr. Davis has displayed both great courage and great skill in his discussion of "which structure mediates which functions." He has at every step, I think, picked the best and currently most plausible hypothesis. I am sure that he does not expect to be 100 per cent correct. I should not be surprised, however, if he touched 95 per cent, and to do that is a tremendous accomplishment.

## TRANSMISSION AND TRANSDUCTION IN THE COCHLEA

## CLINICAL DISCUSSION

John R. Lindsay,

University of Chicago,

Chicago, Illinois

It is gratifying to the otologist to hear of the extensive research being carried on concerning the problems of hearing. Dr. Davis' presentation of evidence pertaining to the physiology of the hearing mechanism within the cochlea is of direct interest in the case of end-organ lesions, but does not lend itself readily to discussion from the clinical viewpoint. I believe it would be more appropriate for the otologist to call attention to a few of the clinical problems which are in urgent need of investigation.

The most common cause of serious hearing impairment in early adult life is the condition known as otosclerosis. The cause of otosclerosis is not known, nor is there any known means by which the progress of the disease can be inhibited. Although tremendous progress has been made in recent years in improving the hearing through surgery in certain selected cases of otosclerosis, there are many cases for which surgical procedures offer little or no help. There are many cases which, because of progressive nerve loss, cannot be helped either by medical or surgical means, and a few for whom the modern hearing aids are inadequate.

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In a case reported some years ago by Professor Nager, the evidence indicated that a meningoencephalitis had been present with direct extension from the subarachnoid space to the perilymphatic compartment of the labyrinth There are also other types of cases in which clinical circumstances suggest that there may have been a direct extension of a virus infection or its toxic effects through the labyrinth windows from the middle ear The factual information regarding this type of injury to the inner ear is scanty In this, as in many other diseases of the ear, there is still a paramount need for histopathologic evidence as to what takes place in the inner ear and in the neural apparatus

One of the diseases which has been most intriguing to the otologist, and also to those of you carrying on research on the function of the cochlea, is that known as Ménière's disease The characteristics of the auditory disturbances in this condition have been unique With the accumulation of histopathologic evidence and the development of hearing tests much has been learned about this condition, however, certain features still remain inadequately explained The basic reason for the hydrops is not settled, and probably will not be finally determined until chemical analysis of the fluids have been further developed Information pertaining to certain features, such as the recruitment phenomenon, has been obtained through experimental procedures, however, the fluctuating low tone deafness seems to have so far eluded an adequate explanation Clinical observation has indicated that a Ménière's disease may exist without vertigo and without producing the distortions of the vestibular portion of the labyrinth characteristically found in those ears which have come from patients who had Ménière's disease with attacks of vertigo Histologic confirmation of this opinion that Ménière's disease may occur without vertigo has been afforded by a case which has recently come through our laboratory In this particular case there was no history of attacks of vertigo The character-

The cause of nerve degeneration associated with otosclerosis is not yet definitely known Dr Cawthorne has presented his view to you on this problem, yet on the basis of the histopathology in some advanced cases of otosclerosis there has been evidence of irritation of the inner ear and both degeneration of the sensory structures and a labyrinthitis ossificans

Factual information is also needed to explain the severe deafness which sometimes follows relatively mild trauma to the head Experimental work has furnished much information relative to acoustic trauma and the effect of high intensity noise on the inner ear, however, none of these experiments has adequately explained the profound deafness, sometimes unilateral and sometimes bilateral, which may result from striking the head on the pavement, for example, without causing unconsciousness and sometimes without evidence of fracture

It appears from the clinical course that in this type of case the pathology differs from that produced experimentally by severe blows to the head It is not explained on the basis of a transverse fracture of the pyramid, since there is no X-ray evidence, and there is sometimes some recovery of function

Another group of inner ear disturbances about which we have had very little information regarding the underlying pathology is due to virus diseases Deafness has been a frequent complication of some contagious diseases, particularly mumps, measles and typhus Sudden severe inner ear deafness has occurred sometimes in relation to a simple upper respiratory infection with or without a non-suppurative otitis media, or as a part of certain less common syndromes affecting also the ocular apparatus, the salivary glands or the central nervous system and meninges There has been an almost complete lack of information as to pathogenesis and pathology The only virus disease in which the histopathology of an inner ear complication has been demonstrated has been measles We have been able to find only two definitive reports on the pathologic picture produced by the measles virus in the inner ear, and we have recently added one bilateral case showing inner ear invasion by the measles virus In this case the finding could be described as an endolymphatic labyrinthitis resulting from direct invasion of the endolymphatic system by the virus by way of the stria vascularis

In a case reported some years ago by Professor Nager, the evidence indicated that a meningoencephalitis had been present with direct extension from the subarachnoid space to the perilymphatic compartment of the labyrinth There are also other types of cases in which clinical circumstances suggest that there may have been a direct extension of a virus infection or its toxic effects through the labyrinth windows from the middle ear The factual information regarding this type of injury to the inner ear is scanty In this, as in many other diseases of the ear, there is still a paramount need for histopathologic evidence as to what takes place in the inner ear and in the neural apparatus

One of the diseases which has been most intriguing to the otologist, and also to those of you carrying on research on the function of the cochlea, is that known as Ménière's disease The characteristics of the auditory disturbances in this condition have been unique With the accumulation of histopathologic evidence and the development of hearing tests much has been learned about this condition, however, certain features still remain inadequately explained The basic reason for the hydrops is not settled, and probably will not be finally determined until chemical analysis of the fluids have been further developed Information pertaining to certain features, such as the recruitment phenomenon, has been obtained through experimental procedures, however, the fluctuating low tone deafness seems to have so far eluded an adequate explanation Clinical observation has indicated that a Ménière's disease may exist without vertigo and without producing the distortions of the vestibular portion of the labyrinth characteristically found in those ears which have come from patients who had Ménière's disease with attacks of vertigo Histologic confirmation of this opinion that Ménière's disease may occur without vertigo has been afforded by a case which has recently come through our laboratory In this particular case there was no history of attacks of vertigo The characteristics of the hearing loss, however, were such that a diagnosis of probable Menière's disease was made. The histologic sections from the affected ear have shown the characteristic hydrops of the cochlear part of the labyrinth, but there was no distortion of the vestibular portion. I am not aware of any other case on record which has afforded definitive information on this particular point.

There are many other problems pertaining to hearing impairment which are far from being adequately explained. One of the greatest problems which has faced the research worker in the field of hearing has been the difficulty in obtaining factual information regarding the pathologic process which has produced the disturbance.

It is obvious that a primary requirement for the understanding of disturbances of function is a complete knowledge of the physiological processes involved in hearing and maintenance of equilibrium. It is, however, evident to the otologist that there are great gaps in information regarding the pathologic states which cause the functional disturbances, and that increased efforts to obtain such inforamtion is an urgent need.

* * *

## WEDNESDAY AFTERNOON SESSION

The International Conference on Audiology convened at 2 o'clock P.M., in the Auditorium of the Washington University School of Medicine, St. Louis, Missouri, Dr. Joseph Erlanger, Washington University School of Medicine, presiding.

## NEURAL MECHANISMS IN AUDITION

Robert Galambos,
Walter Reed Army Institute of Research,
Washington, D. C.

My discussion of Listening and Pitch Perception will of necessity be brief, for in the 30 minutes at my disposal I shall be obliged to paint the picture with a very wide brush. Recently published accounts of these matters are, however, available for those of you who wish more details.[1,3,17-18]

## LISTENING

I am sure all of us here recognize the distinction between "listening" and "not-listening." During this Congress we have heard the phenomenon referred to repeatedly, with such terms as "central deafness," "central factors in deafness" and "hearing but not perceiving" being employed. The main idea behind these concepts is that while the cochlear apparatus within the temporal bone may be entirely normal and fully capable of arousing impulses in the auditory nerve, a central auditory apparatus must also be acting in a special and particular way if sounds are to provoke responses from animals and men. A moment's reflection tells us that the brain must indeed be organized in one way when we listen and in another way when we do not. One of the tasks of the auditory neurophysiologist, it seems to me, is to define as best he can the difference between these two states.

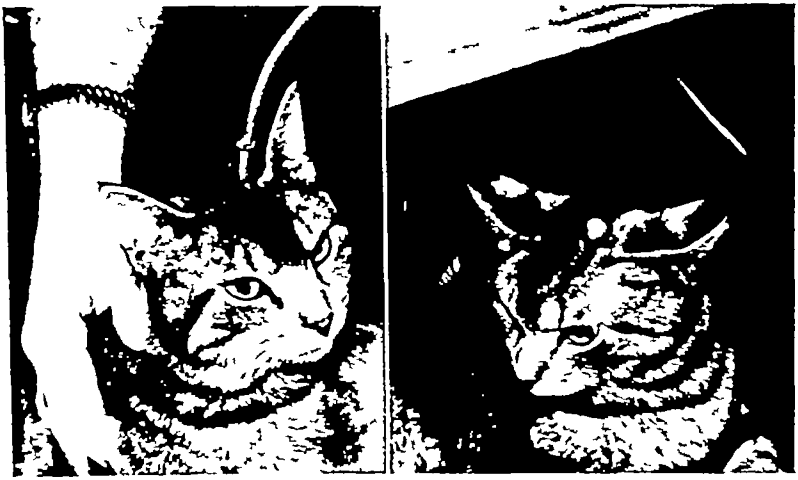

Fig. 1. Cat with eight Implanted Electrodes for E.E.G. Studies.

Various attempts to do this have employed cats like that shown in Fig 1 [7 9,10] Wire electrodes were implanted in the brain many weeks earlier, and these were led to the outside through the connector seen attached to the skull In this way the E E G was made available for study whenever desired, and the animal could be examined at any time in the unanesthetized state

Fig 2 shows some records from such an animal The upper line in each section shows the time at which an auditory

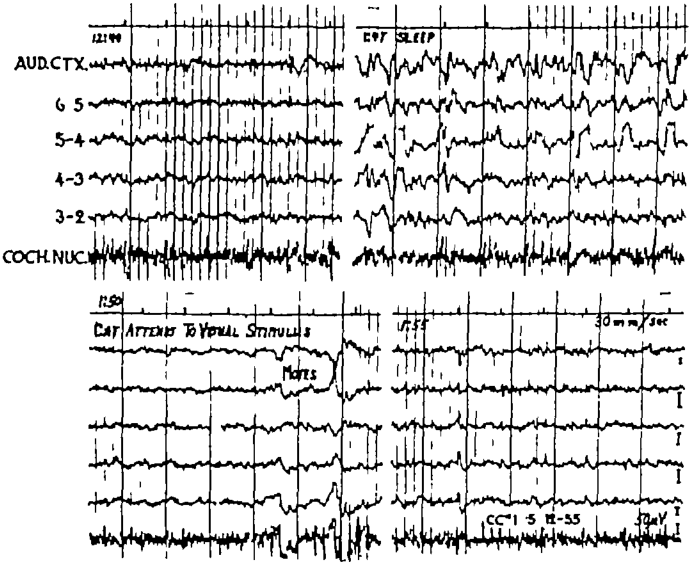

Fig 2 Brain responses to click stimuli from a cat like that shown in Fig 1 Electrodes 2 through 6 are located 2 mm apart in the Horsley-Clarke A-18 plane 6 and 5 are in subcortical white matter and 4 3 and 2 are in the caudate nucleus The size of the brain response obtained to a constant click stimulus seems to depend upon such variables as sleep and attentiveness

stimulus—in this instance a click of moderate intensity—was presented through a loudspeaker Notice that the E E G response to this sound is not uniform in size in the cochlear nucleus or the auditory cortex, and that on occasion the stimulus evokes responses from parts of the brain (caudate nucleus) not considered in text books to be part of the auditory system of neurons The study of many records such as this suggests the conclusion that auditory stimuli of constant strength do not invariably produce the same effects upon the brain, nor are their effects limited to those brain areas conventionally considered to be auditory in function

The demonstration that a fixed stimulus may yield a fluctuating brain response leads naturally to the question of whether the response is large when the animal "listens" and less so when it does not This idea is clearly suggested in

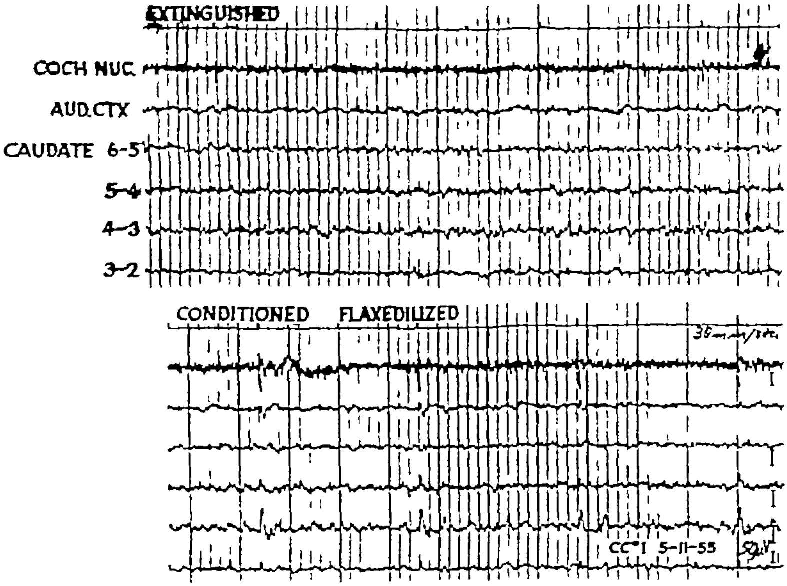

Fig 3 Effect of a simple conditioning procedure upon the amplitude of response evoked by click. Upper record small amplitude responses from animal exposed to click day and night for many days lower record larger amplitude to same click after it had been paired with shock To prevent muscle artifacts the animal was treated with a curare-like substance prior to the lower recordings

Fig 2, where the cat attends to a visual stimulus, the animal is probably not attending to the click at that time, and the diminished size of the response to clicks may be taken to correspond with this fact

In the attempt to explore this possibility systematically the recordings of Fig 3 were made The records in the lower part of that figure were made after the clicks had been paired with shocks to the skin Responses to the clicks are uniformly large in size It was our intention to condition the cat to expect a shock in the presence of the click, and apparently the clicks did ultimately become a signal for the cat that an unpleasant event was about to occur The records in the upper part of the figure, on the other hand, had been made at an earlier time when the cat had been in the presence of the same click for many hours, and seemed to be paying no attention whatever to them, the E E G responses to clicks turn out, as expected, to be relatively smaller and considerably less widespread throughout the brain in the habituated as compared to the conditioned state [7]

The variation in amplitude of the auditory cortical responses in Fig 3 will come as no surprise, since it is generally thought that the cortex participates in some important way in the attentive function under exploration The demonstration that much the same phenomenon takes place in the cochlear nucleus, however, demands that the auditory nervous system throughout its entire length be under the control of neural mechanisms that modulate incoming messages, allowing impulses to pass at one time and preventing their passing at others Unfortunately, we do not completely understand what these controlling mechanisms actually are, but an examination of the known anatomy of the auditory system provides some speculative possibilities

Fig 4 shows, on the left, the classical ascending fiber pathways shown in most text books, as well as the newer routes by way of the reticular formation and to the cerebellum that have come to be known over the past 15 years (see[3]) On the right, by contrast, are shown the fiber tracts that descend from the cortex to end up finally in the cochlea itself This descending system was known in part to Cajal, to Lorente de No and to others of the classical schools of neuroanatomy, but the modern concept of its course and distribution is due largely to the efforts of Dr Grant Rasmussen His most notable contributions[12 13] have shown that a bundle of fibers originating in the region of the superior olivary nuclei terminates on or near the internal hair cells This olivocochlear bundle represents the terminal line in the neural path that originates at the cortex, descends in close approximation with the classical ascending auditory fibers, and makes synaptic connections in many, if not all of the auditory nuclei One may speculate that it is through the action of this descending collection of fibers that modulation of the incoming messages occurs, something being "fed" or even "fed back" into the system to provide the control Such speculations at the present time also involve to varying degrees the limbic system in the forebrain and the reticular formation in the mesencephalon, but these details need not be stressed further Instead, let us consider some evidence that the olivocochlear bundle of Rasmussen has a definable physiological function in the cat, and by inference in any other animal (including man), with a bundle of Oort in its VIIIth nerve complex

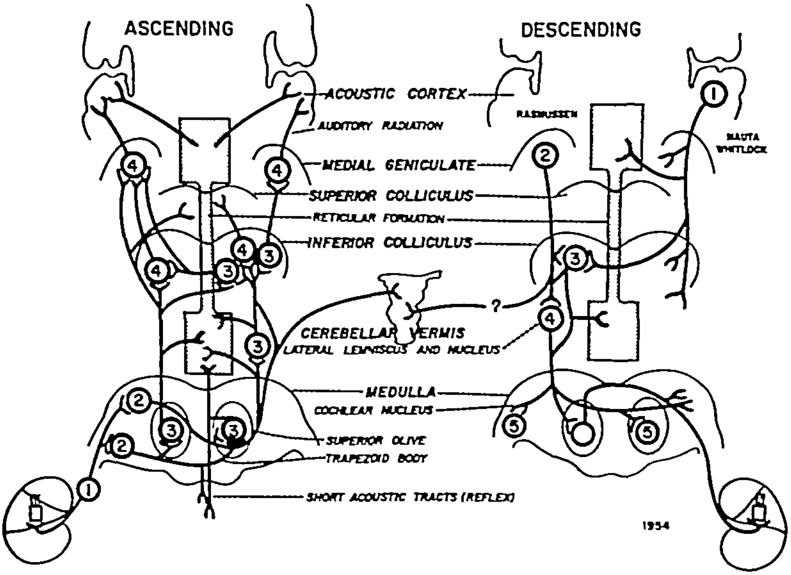

Fig 4 Diagram of the auditory pathways showing ascending and descending connections

Fig 4 summarizes the essential feature of this study,[4] showing that the amplitude of the auditory nerve response to a click stimulus is significantly reduced if a barrage of impulses is simultaneously arriving at the cochlea via the olivocochlear bundle  This final link in the descending chain of neurons thus has an inhibitory effect upon the auditory system, preventing the arousal of the expected amount of nerve activity to a standard click stimulus  It should be noted that this inhibition was demonstrated by delivering

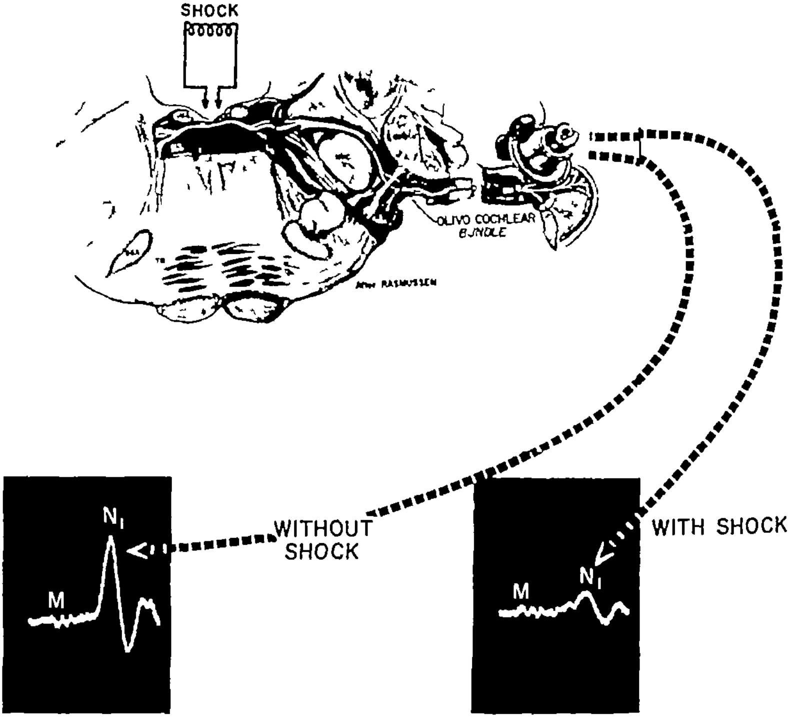

Fig 5  Anatomical plan of the olivocochlear pathway and illustration of its function  The cross section shows cells of origin (OSA) and anatomical course of fibers to the cochlear spiral  Shocks applied where the fibers decussate markedly reduce the amplitude of the auditory nerve discharge ($N_1$) evoked by a click without influencing the hair cell response (M)

electrical shocks to the medulla of anesthetized cats, and that it has not as yet been shown to occur naturally in normal animals, so we cannot be certain in extrapolating these data to the normal case, nevertheless, the final link in the descending system acts as an inhibiting mechanism in these physiological preparations, and from this fact we may, perhaps, be permitted to infer that the probable role of the entire system in the normal animal is at least in part an inhibitory one.

These first efforts to study the problem of "listening" can be summarized as follows. The attentive animal is characterized by large E.E.G. responses spread throughout its brain, areas being included that ordinarily are not considered to be part of the auditory system. The inattentive animal shows responses in fewer brain locations, and these are small in size. The variation in size occurs throughout the auditory system, being apparent even at the cochlear nucleus, the first synapse in the auditory system. The descending pathway represents a possible neural mechanism for causing the amplitude variations, and its final link, the olivocochlear pathway, is known to function as an inhibitor. Much obviously remains to be done, however, before the problem is finally solved.

## PITCH PERCEPTION

Of all the problems of hearing, that of how we perceive pitch has undoubtedly received the lion's share of attention by experimentalists. Many recent reviews of this topic are available,[1, 3, 1-18] and so my efforts today need not attempt comprehensiveness. Instead let us consider some old and new studies with microelectrodes that seem to illustrate the major principles thus far elucidated. These microelectrodes, you will recall, allow the action potentials of a single brain cell to be isolated for study. The way the cell responds to the variety of sounds to which the ear is subjected, constitutes the raw data out of which an understanding of the brain is to be fashioned. If we collect data from a sufficiently large number of such cells we can hope to create a complete and satisfactory picture.

Fig. 6 presents some of the earliest records taken from the auditory system with this technique.[5] When the words "VIIIth nerve" were spoken in the vicinity of the cat, a unit in the cochlear nucleus reacted briskly, as is shown there. It has since been repeatedly demonstrated that auditory units in all the auditory nuclei are similarly sensitive to sounds, and when pure tones are employed they respond to a limited and restricted band of them. This fact is demonstrated for

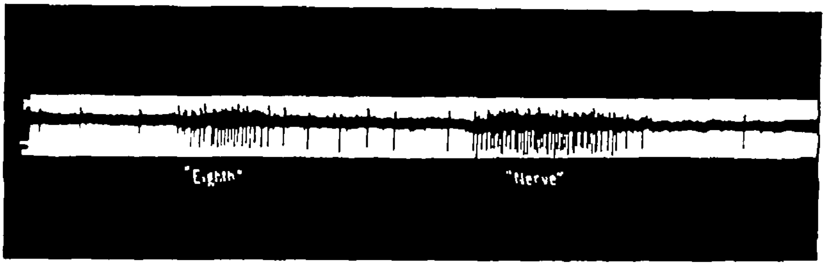

Fig 6 Response of a single cell in the cochlear nucleus to spoken words Microelectrode recording from anesthetized cat

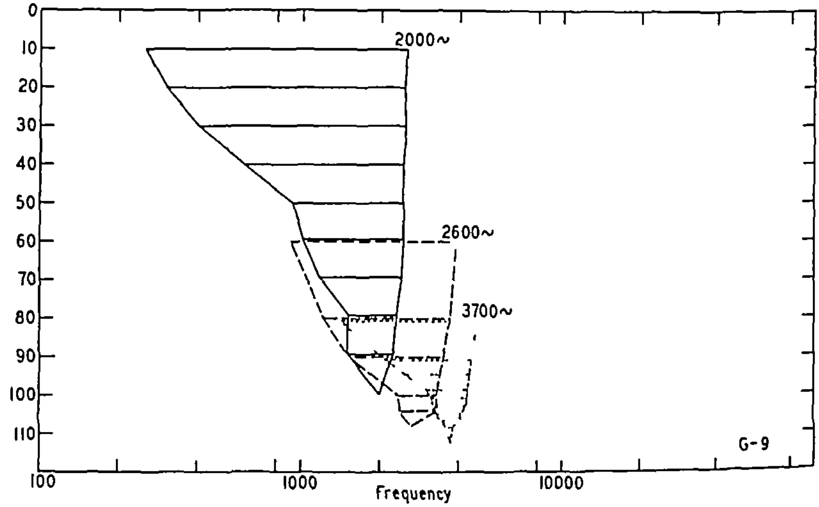

Fig 7 Response areas for three separate cells in the cochlear nucleus of the anesthetized cat Ordinate intensity in db below reference level for tones given on abscissa The 'best frequency of each cell is written next to the triangular response area that encloses all tones found adequate for its stimulation

three units in Fig 7, where the tones that excite any given unit are seen to fall in a limited part of the sound spectrum The triangular "response area" thus experimentally defined proves conclusively that auditory units function physiologically in the manner suggested by their anatomical connections, namely, by responding to limited bands of tones The basic idea of Helmholtz, which was that some unique spatial correlate exists in the brain for each perceived tone is, therefore, essentially confirmed, although the details of how this comes about is a somewhat more elaborate story than I can give you here (but see [1, 3, 15, 16])

Fig 8 shows the experimental demonstration of the place principle in the case of the cochlear nucleus [14] The path of a microelectrode track is shown there in a saggital section of the nucleus The electrode entered the dorsal cochlear nucleus from behind and proceeded successively through the posterior and anterior ventral cochlear nuclei The numbers in Fig 8 represent the tone frequencies found by physiological methods to be best represented at the indicated position It is clear that an orderly arrangement exists in the various segments of this complex nuclear mass A similar tonotopic arrangement has been uncovered throughout the auditory system wherever it has been sought experimentally

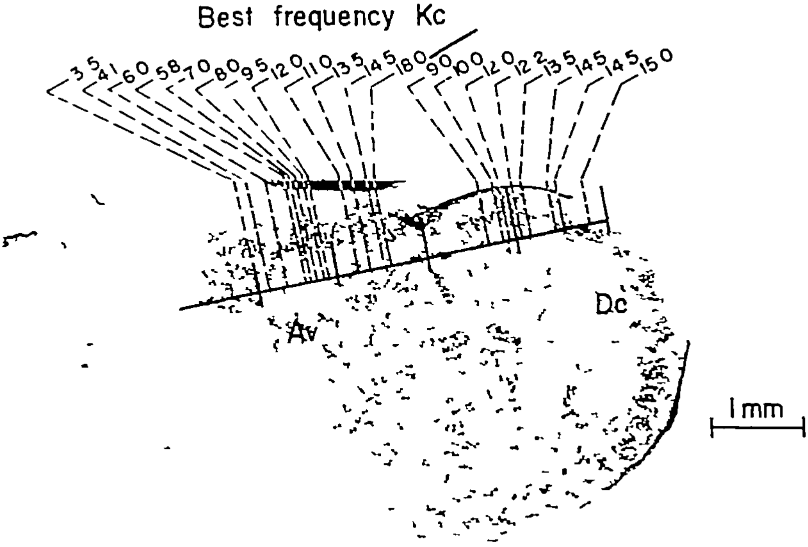

Fig 8 Plot, on a saggital section of the cochlear nuclei of the cat, of the best frequencies encountered during a particular microelectrode puncture Note orderly decline of frequency in both the dorsal (Dc.) and the anterior ventral (Av ) segments indicating that projection of the basilar membrane to this nuclear mass is tonotopic

We can conclude, therefore, that the evidence is heavy in support of the idea that the place in the brain where a tone

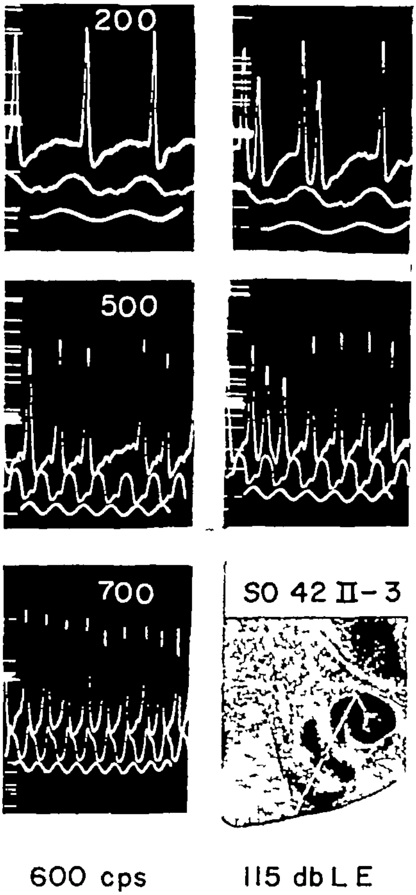

Fig 9 Responses of a single cell to tones Anesthetized cat Electrode location lower right accessory superior olivary nucleus Each segment of the figure shows at left the spontaneous activity of the unit and on the swept traces the unit response (top line) the cochlear round window response (middle) and the electrical signal delivered to the earphone (bottom The tone frequency employed is written on the left member of each pair of records to which it pertains The best frequency for this unit was 600 cps the stimuli were applied to left ear with recording on the right side

produces its effects is somehow important for our ability to perceive pitch, but what about that other persistent idea of how tone frequency is handled, namely, that each nerve fiber responds at the frequency of the tone? Fig 9 shows that, to a remarkable extent, this idea is correct also The unit pictured there was isolated in the superior olive[6] It responded to tones up to 1100 cps, and the pictures make it clear that it often did so by discharging once to each sound wave cycle The pictures also make it evident, however, that the unit sometimes skipped responding, and that it would on occasion respond twice to a single sound wave cycle The facts, nevertheless, unequivocally support the idea that tonal frequency can be centrally represented as nerve discharge frequency We do not as yet know precisely how to evaluate the relative importance of the two principles—place and frequency of nerve discharge—in the mechanism of brain action that results in pitch perception We can be certain only that the frequency principle must be of limited utility for tones above 1000 or 2000 cps

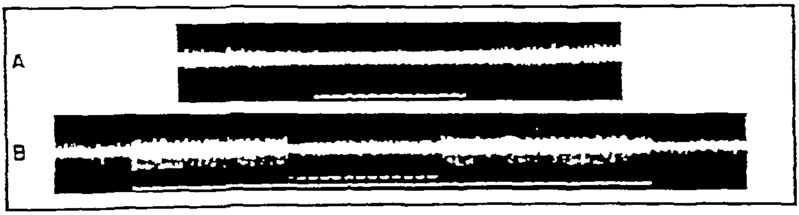

Fig 10 Suppression of cochlear nucleus cell responses by tones Anesthetized cat. A.—The spontaneous activity of a unit disappears so long as a tone (white line below record) is on B—A unit excited by one tone (long white line) stops completely so long as a second tone (short line) is simultaneously sounding

Besides the place and frequency principles there are at least two other facts about the auditory brain that almost certainly are relevant to the pitch problem The first of these is that a low tone activates a larger amount of the auditory brain than does a tone of high frequency This is true, because the pattern of cochlear motion aroused by low tones spreads from base to apex along the basilar membrane, thus sweeping across the entire neural complement of the cochlea The pattern evoked by high frequency tones, by contrast, is restricted to the base The consequences of this fact are not entirely understood, but it is already clear that any partial damage to the VIIIth nerve that involves fibers from the various parts of the basilar membrane in equal proportions yields a selective loss of hearing for high frequencies[8, 11]

The second ancillary fact is illustrated in Fig 10 We ordinarily think of the auditory stimulus as creating excitation, or increased nerve activity, when it is presented to the ear This is certainly the case for many single units in the brain, as can be seen in Figs 6 and 9 In Fig 10, on the other hand, what the stimuli do is to suppress the ongoing activity rather than to create more of it (see[2]) This inhibitory effect of tones is a general phenomenon observable at all levels in the auditory system including the cortex

This demonstration that a particular tone causes certain units to stop firing and others to fire more briskly, probably means that the overall effect of the tone is to create areas of activity interspersed among cellular areas in which activity has been suppressed Presumably the exact locations and extents of such excited and inhibited areas are of significance as central correlates of the tonal frequency (see[3]), but no clear picture of how this exactly occurs can yet be given

There are, then, the four factors known to play some role in the central mediation of the experience of pitch The well-known place and frequency principles clearly are in operation The "place" involved by a given tone must, however, be conceived as collections of neural loci, in some of which increased activity occurs, whereas decreased activity occurs in others The configuration of excited and inhibited "places" varies as the tone frequency changes, and this geographical (tonotopic) correlate for pitch is the one most securely established by experimental data The "places" involved, finally, are more extensive and widespread through the auditory nuclei when the tone is low as opposed to high in frequency How the central nervous system produces the sensation of a tone out of these bits and scraps of information remains a complete mystery

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## PHYSIOLOGICAL DISCUSSION

Ichiji Tasaki,

National Institute of Neurological Diseases and Blindness,

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Dr. I Tasaki Dr Galambos has just given us a very interesting survey of the problem of how the nerve fibers and cells in the auditory pathway transmit nerve impulses to the central nervous system He has shown us clearly that the function of the auditory pathway is not only to transmit messages to the central nervous system but also to assort and classify the messages before they reach the brain, or sometimes, to eliminate some of the messages before they reach the cerebral cortex Now I should like to discuss the problem before us very briefly from a slightly different angle, namely, in relation to our present day knowledge of more general mechanisms found in the nervous system

Sometime ago, Dr Davis and I demonstrated the fact that the auditory nerve fibers arising in the basal turn of the guinea pig cochlea respond to tones of any frequency, high and low, while the fibers originating in the apical turn respond only to low frequency tones (slide) These nerve impulses in the individual auditory nerve fiber obey the all-or-none law They will not stop until they arrive at (or near) the synapses in their pathway The behavior of these synapses in the auditory system is probably very similar to that of other excitatory or inhibitory synapses in the nervous system, therefore, physiological studies on the auditory pathway are , in a sense, a sort of experimental study on synaptic transmission in the nervous system If the pattern of the nerve impulses arising in the cochlea is accurately given, the fate of these impulses will be determined simply by the structure of the nervous system This part of the problem is not specific to the auditory system

The problem dealing with initiation of nerve impulses in the cochlea is, on the contrary, very specific to the auditory system, because the structure of the inner ear is very different from that of other mechanoreceptors Let us take a look at a picture illustrating the familiar structure of the cochlea (slide) When we introduce a glass pipette electrode into various parts in the cochlea, it is found that the electric potential in the space occupied by endolymph is 80-90 mv positive to that of the perilymph (Békesy) It appears to us that the fluid in the space between the basilar membrane and the reticular lamina is 70-80 mv negative to the perilymph

These dc potentials can be interpreted as devices for increasing the sensitivity of the nerve fibers to electrical stimuli Microphonics and other slowly changing potentials are undoubtedly signs of intermediate processes which link the mechanical events with the process of initiation of nerve impulses

A few days ago Dr Rasmussen gave us a special strain of guinea pigs, waltzing guinea pigs He gave us three of them, and we used four, that means we took one more after he left to attend this meeting These guinea pigs show no sign of microphonic responses They have no hair cells in the cochlea The story that the hair cells are responsible for generation of microphonic responses is safe, but, we found a dc potential of about 80 mv in the endolymphatic space and also a strong negativity in the space between the reticular lamina and the basilar membrane A few years ago somebody around here made an attempt to attribute the endolymphatic dc potential in the cochlea to the function of the hair-cells That was a mistake, my mistake At present there is no doubt that the positive potential is generated by some oxidative metabolism in the stria vascularis

In conclusion there is a very intriguing problem in Dr Galambos' presentation. That is the problem of how the electric responses in the auditory nerve fiber are suppressed by stimulation of the olivocochlear nerve bundle In general, it is extremely difficult to suppress an all-or-none response in the nerve fiber All the inhibitory processes that have been demonstrated in other parts of the nerve system take place at the site of initiation of nerve impulses, namely, at the pace-makers

I am assuming that Dr Galambos' electrical stimuli were limited to the fibers in the olivocochlear bundle Under this assumption, the most probable explanation of the phenomenon is to attribute it to secretion of some inhibitory substance which raises the threshold of the nerve endings to mechanical stimuli A somewhat similar phenomenon has been reported recently by Dr Leowenstein in the mechanoreceptor in the skin (*Nature,* 178 1292, 1956)

# ANATOMICAL DISCUSSION OF THE PAPER GIVEN BY DR GALAMBOS

GRANT L RASMUSSEN,

*National Institute of Neurological Diseases and Blindness,*

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I have closely followed the studies of Dr Galambos during the past several years, and have often wondered about the function significance of this strange system of auditory neurons which course backward in an unorthodox fashion

It is not necessary to review the general plan of the ascending and descending auditory pathways, since Dr Galambos has already done this with the aid of his Fig 4 To be sure his schema of the circuits was necessarily simplified for his presentation

Our main interest presently concerns the less well-known descending or recurrent conduction chain of auditory neurons which extends from the cerebral auditory cortex to the cochlea itself It has been possible to reveal this system of fibers by means of axonal and terminal degeneration methods[1 2 3 4] These fibers are for the most part intermixed with those of the ascending system, which constitutes by far the greater number of fibers The recurrent fibers hold constant positional relationship and, moreover, are interconnected in an orderly fashion, projecting from definite cell groups of higher levels to particular cells of any one of several auditory nuclei For example, certain neurons of the inferior colliculus and dorsal nucleus of the lateral lemniscus connect bilaterally with particular cell groups of the dorsal cochlear nucleus, and of the superior olivary complex, thus we see evidence of a certain specificity in the descending system, the meaning of which is not understandable to me at this time

Having described some of the general anatomical features, I will now present a more detailed description of the pattern of distribution of the descending system, as found at the level of the brain, which holds most interest at this time I show a figure of a transverse cut of a cat's medulla oblongata at the level of the olivary complex and olivo-cochlear bundle, which includes also the cochlea This is similar to Fig 5, shown by Dr Galambos, except that here the recurrent fibers coming from the inferior colliculus are displayed

Here within the confines of the circumscribed area indicated, are scattered fibers which degenerate following a lesion of inferior colliculus and/or dorsal nucleus of the lateral lemniscus Some of these fibers enter and terminate in that part of the olivary complex that has been previously determined as the site of origin of the olivo-cochlear bundle, the fibers of which terminate in the cochlea perhaps about hair cells, however, substantial anatomical proof is still lacking on this point

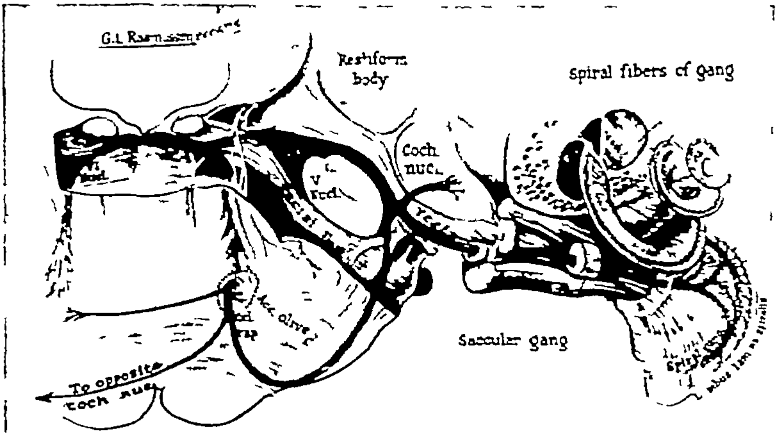

Fig 1.

While some fibers end in the medial two segments of the olivary complex, a very impressive number of fibers continue on through the trapezoid body to reach and disperse themselves within the dorsal cochlear nucleus of both sides

This may well be one of the important pathways concerned with suppression of neural activity of the cochlear nucleus from higher levels, as has been mentioned by Dr Galambos

This efferent packet of fibers that enters the cochlear nucleus would seem to be identical with that first described by Held,[5] and later by Lorente de Nó,[6] in Golgi preparations While both recognized its efferent nature, neither were able to determine whence it came

Finally, I would like to mention that in recent studies I have been able to demonstrate anatomically several other recurrent contributions to the cochlear nucleus that originate from brain regions not usually considered auditory in function

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## CLINICAL DISCUSSION OF THE PAPER GIVEN BY DR GALAMBOS

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I am afraid that what I have to say from the clinical point of view is not very satisfactory, because I have been more concerned with vestibular disturbances than with those of the cochlea, however, I will refer to the lesions in the brain stem, lesions due to tumors, encephalitis, hemorrhages and concussions Between 1950 and 1957 we have seen 76 cases of this kind at the Neurosurgical Institute in Santiago, Chile The contrast between the rich vestibular symptomatology and the poor cochlear symptomatology is surprising

Disorders of the equilibrium, spontaneous nystagmus and positional nystagmus, and marked alterations in the caloric responses were found in almost 100 per cent of the cases On the other hand, the audiometric examination was always normal, or almost normal, even in those cases in which a bilateral vestibular paralysis was found Precisely this cochlear and vestibular dissociation, in which the vestibular nerve is paralyzed and the cochlear is normal, is an important sign of a destructive lesion in the vestibular area of the floor of the fourth ventricle

We have been anxious to see what happens when only the cochlear nucleus at the medulla is involved We believe that the following case shows something A 20-year-old man was admitted at the Neurosurgical Institute with the suspicion of a brain tumor After an exhaustive neurological examination, and after a two-month follow-up, the diagnosis of encephalitis due to virus infection was made Before becoming ill this young man never complained of hearing loss nor loss of balance

The audiogram showed a normal left ear and a hearing loss of the ascending type in the right ear with no recruitment, but with diplacusis At the same time the calorigram showed a total paralysis of the right vestibular branch and paresis of the left vestibular branch Even more, with water at 18 degrees during a 60 second irrigation a perverted vertical nystagmus was seen

The patient also had spontaneous nystagmus to the left, a marked loss of balance and involvement of the VIth nerve on both sides In the absence of recruitment, bilateral cochleo-vestibular dissociation, perverted nystagmus, and neurological involvement of central nature of both VIth nerves, we diagnosed a partially destructive lesion of the floor of the fourth ventricle Not only a partially destructive lesion of the vestibular area, but also a partially destructive lesion of the right cochlear nucleus, was found

This efferent packet of fibers that enters the cochlear nucleus would seem to be identical with that first described by Held,[5] and later by Lorente de Nó,[6] in Golgi preparations While both recognized its efferent nature, neither were able to determine whence it came

Finally, I would like to mention that in recent studies I have been able to demonstrate anatomically several other recurrent contributions to the cochlear nucleus that originate from brain regions not usually considered auditory in function

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## CLINICAL DISCUSSION OF THE PAPER GIVEN BY DR GALAMBOS

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I am afraid that what I have to say from the clinical point of view is not very satisfactory, because I have been more concerned with vestibular disturbances than with those of the cochlea, however, I will refer to the lesions in the brain stem, lesions due to tumors, encephalitis, hemorrhages and concussions Between 1950 and 1957 we have seen 76 cases of this kind at the Neurosurgical Institute in Santiago, Chile The contrast between the rich vestibular symptomatology and the poor cochlear symptomatology is surprising

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Apparently these lesions were irreversible, because after six months, although the patient was much better from the neurological point of view, the functional examination of the VIIIth nerve gave exactly the same results

We believe, then, that the deafness due to a lesion of the cochlear nucleus is very similar to the deafness due to an acoustic tumor Unfortunately, we have not done the speech tests in our patients because, as I have already pointed out, we have been more concerned with the vestibular system

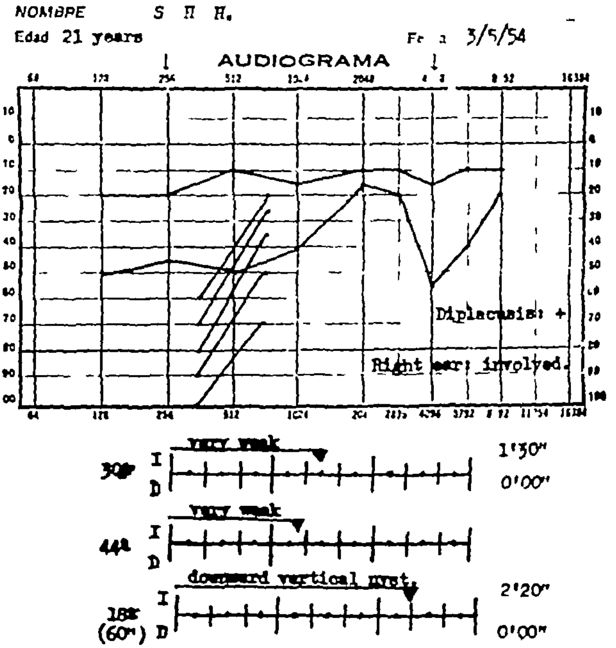

Fig 1

Dr Lindsay has described what he calls "deafness of sudden origin and indefinite etiology" It is possible that some of these cases are due to lesions in the cochlear nuclei

A 19-year-old woman awakened one morning with strong tinnitus and total deafness in the right ear She also had some dizziness and loss of balance, but she could continue her school duties We saw her four months after this had happened The otoscopic examination and the vestibular tests were normal

The audiogram showed a nerve type of hearing loss at right, with absence of recruitment and with a normal differential limen, which does not correspond to a lesion in the end-organ

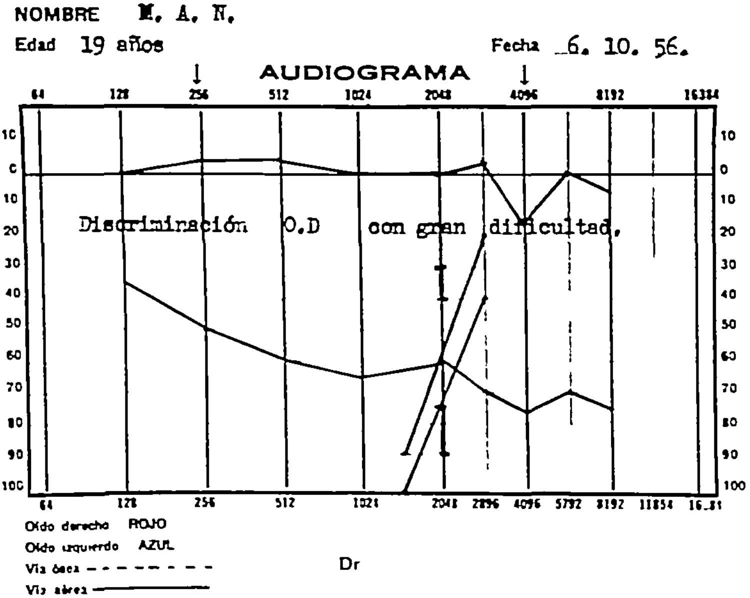

Fig 2

The fact that this deafness of sudden origin and indefinite etiology is possible of a complete or partial recovery, as we have seen in a few instances, suggests that the lesion is in the cochlear nucleus and not in the end-organ Obviously we are not talking about endolymphatic hydrops When recovery takes place, this happens in the first three weeks, not after We have seen patients who had a complete unilateral deafness, and within nine to 15 days were totally recovered We may assume that if the organ of Corti had been damaged no recovery would have been possible

Patients with stem brain lesions are not numerous, and when one is found, usually its general condition is bad As we are asked for a localization diagnosis, we go through all the functional examination of the VIIIth nerve, with particular emphasis on the equilibrium tests, cerebellar and vestibular tests (central and peripheral), which are most important for our purpose, however, we feel now that if the neurosurgeon is not in a hurry, and if the patient is not too bad, we can go through a more complete audiologic examination in order to correlate the clinical findings with the histopathological ones, as we have been doing with the vestibular disorders

For example, here is a case in which the cochlear study was very poor as compared with the vestibular interpretation A 47-year-old man had an adenocarcinoma of the thyroid gland with multiple metastasis in the lungs and in the central nervous system He died before any surgery was performed The VIIIth nerve examination showed, as usual, a very rich vestibular symptomatology, which led us to the diagnosis of a partially destructive lesion of the right vestibular area on the floor of the fourth ventricle According to the pathological findings, the diagnosis was correct, and an 8 mm diameter metastasis had partially destroyed the right vestibular nuclei, but we verified a peculiar hearing loss which we could not interpret

The audiogram showed that this patient had a slight hearing loss on left ear and moderate deafness on the right, with a Weber lateralized to the right The middle ears were normal The report of the pathologist showed that a small metastasis involved the right olive in the medulla

Another case, a 42-year-old man, had a clear symptomatology of a brain tumor headaches, vomiting and very marked papillo-edema, but the neurologists were doubtful whether the lesion, the tumor, was in the anterior or posterior cerebral fossae

If the neurological symptomatology was puzzling, the results of the VIIIth nerve examination were even more difficult to understand

He had no hearing at left, but the vestibular branch, ac-

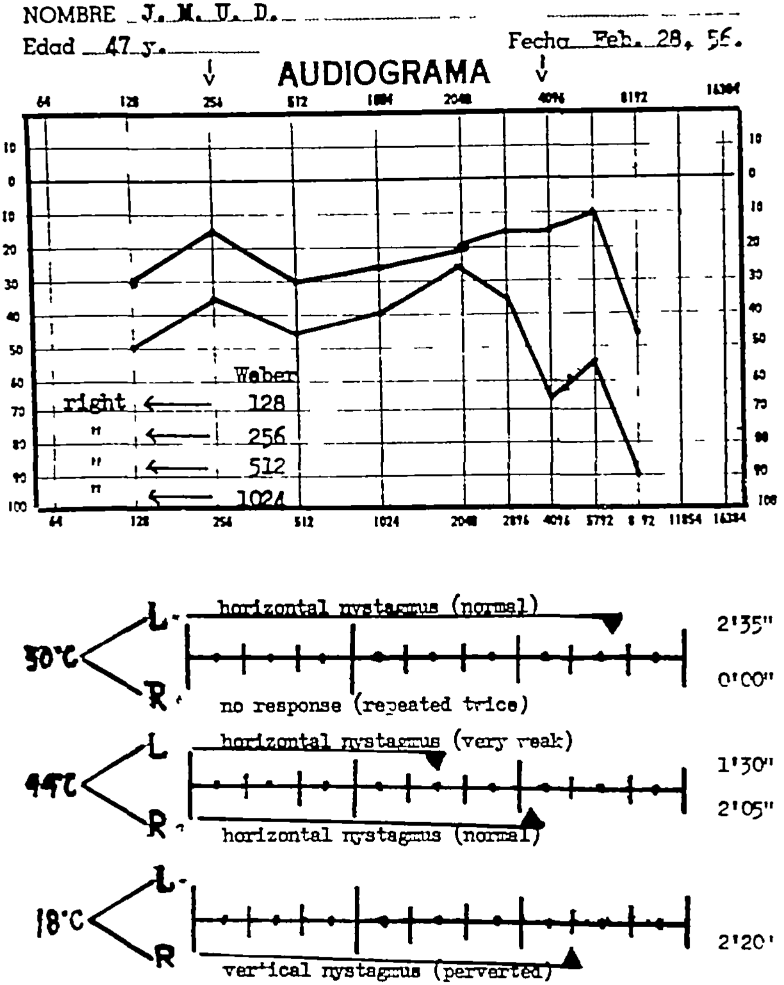

Fig 3

cording to the caloric response was normal On the right ear he had a moderate hearing loss, but no vestibular response Besides this inverted dissociation, he also had *a*. spontaneous nystagmus to the left, *b* positional nystagmus, *c* complete loss of balance—could not stand upon his feet, *d* bilateral hypotony, and, *e* ataxia in the finger-nose tests and adiadokocinesia These cerebellar symptoms were bilateral

From time to time we get cases such as this, in which the otoneurological diagnosis is almost impossible, because there is a cochlear paralysis with normal vestibular in one ear, and a cochlear paresis with a vestibular paralysis in the opposite ear As though this were not enough, the patient had a definite central vestibular symptomatology and bilateral cerebellar symptoms

You may ask what did the electroencephalogram show? It showed abnormal activity in the right cerebral hemisphere

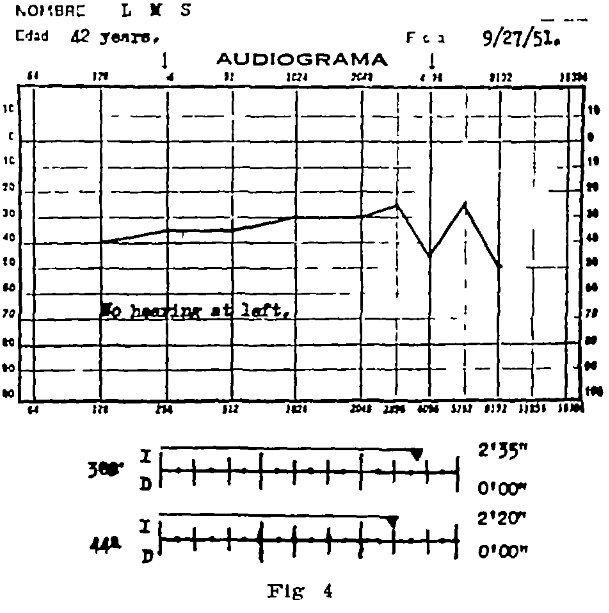

Fig 4

At the necropsy a large astrocytoma in the right cerebral hemisphere was found It was a large, deeply located tumor which strongly compressed the brain stem at the incissura tentorii This was undoubtedly the cause of the central vestibular symptomatology The pathologist found that the tumor had invaded the right medial geniculate body and considered this lesion responsible for the left total deafness and right partial deafness

The contrast between the rich vestibular symptomatology and the poor cochlear symptomatology in cases of brain stem lesions is surprising I should say rather that it is surprising the contrast between the attention we have given the vestibular disorders and the very reduced interest we have shown in the cochlear disorders

If any conclusion can be drawn out of these clinical observations, it is that, until the present moment, very few efforts have been made to learn what actually happens to the auditory function when there is a lesion of the brain stem

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# FUNCTIONS OF THE AUDITORY CORTEX

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Illinois

Because of the lack of appropriate clinical material, most of our knowledge of the functions of the auditory projection areas of the cerebral cortex must come from experiments done on animals other than man In the last fifteen years, considerable progress has been made in animal investigations Several factors have contributed to this progress

*1* The use of electrophysiological recording and stimulating techniques to define more exactly the auditory pathways and centers in the central nervous system, *2* the use of new techniques of experimental surgery, *3* the development of improved methods of testing auditory discrimination, *4* the application of standard neuroanatomical procedures to discover new details of cortical and thalamo-cortical organization

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*Research on hearing which is done in The Laboratory of Physiological Psychology is supported by the Office of Naval Research and by a grant from the Sonics Research Foundation.

In the following paragraphs some of the results of recent studies which have investigated the role of the auditory cortex in sound discriminations, are briefly summarized Particular attention will be given to experiments done in our laboratory with only occasional reference to related studies done by other investigators Emphasis will be placed upon experiments, in which behavioral methods were used to test auditory discriminations before and after partial or total ablation of auditory cortex Since the auditory nervous system of the cat has been more thoroughly explored than that of any other animal, I shall confine most of my discussion to studies in which the cat was used as experimental subject Brief mention will be made of parallel studies which have been done on the monkey

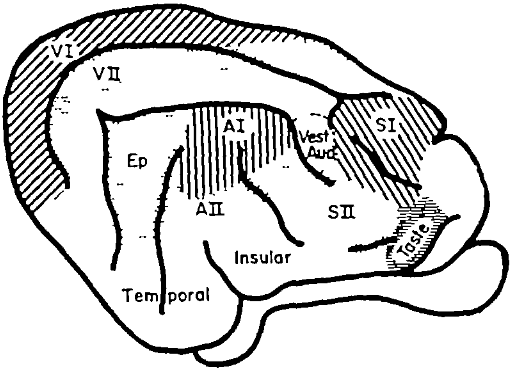

Fig 1 Cerebral cortex of the cat showing auditory areas I II, and Ep the insular-temporal region and projection areas of other sensory systems

The auditory cortex, as it has been defined for recent experiments, is shown in Fig 1 It consists of the areas labelled AI, AII, and Ep This map is based upon results from electrophysiological, cytoarchitectural, and retrograde degeneration studies [1 2 3 4]

In 1943, Kryter and Ades[5] reported that the absolute thresholds of the cat, as tested in a conditioned avoidance situation, were unchanged by bilateral ablation of a region which included all of AI, AII and Ep They made tests only in the frequency range from 125 c p s through 8000 c p s, but there is no later evidence to suggest that losses would have occurred for higher frequencies which the cat hears * A loss of the learned habit occurred as a rule after the bilateral cortical ablations, but relearning was at least as rapid as initial learning

In similar studies, Raab and Ades[7] and Rosenzweig[8] have shown that no loss in capacity to discriminate small changes in intensity occurs after bilateral ablation of AI, AII, and Ep Again the learned habit is affected, but post-operative relearning is rapid

Several studies have shown that the auditory cortex of mammals (at least of the cat, dog and monkey) has a tonotopic organization, *i e*, as measured by electrophysiological recording from gross electrodes a given point on the cortex has a lower response threshold for a particular frequency, or narrow band of frequencies, than for other frequencies in the audible range[9 4 10] Because of this tonotopic organization, it has often been suggested that the auditory cortex may be particularly important for discrimination of changes in frequency

Experiments done by Meyer and Woolsey,[12] and by Butler, Diamond, and Neff,[13] have shown that this is not true Fine discriminations of frequency can be made after complete bilateral removal of AI, AII, and Ep

For a number of reasons, a particularly important one being a consideration of experimental evidence on functions of visual cortex, it might be inferred that the auditory cortex plays an important part in pattern discrimination This inference is true, at least for discrimination of temporal patterns of tones Diamond and Neff[14] have shown that after complete bilateral ablation of AI, AII, and Ep, cats cannot discriminate two tonal patterns, one consisting of three tonal pulses arranged in the sequence, low-high-low, and the other of the same tones presented in the sequence, high-low-high If a region corresponding approximately to AI is ablated bilaterally, the animal can make this pattern discrimination and, in fact, shows no post-operative loss of the learned habit. If all but a small remnant of auditory cortex is ablated bilaterally, there is amnesia for the learned habit, but relearning occurs. Jerison and Neff[15] have reported similar results for the monkey.

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*It has been shown that cats can learn to respond to tones at least as high as 60 000 c p s[6]

Another kind of discrimination, in which a deficit has been shown to occur after ablation of auditory cortex, is localization of sound in space. Neff, Fisher, Diamond, and Yela,[16] and Neff, Arnott, and Fisher,[17] have shown that cats are deficient in ability to localize sound in space after bilateral ablation of all or even of part of the auditory areas I, II, and Ep. After complete ablation of these areas, an animal will localize accurately an angle of about 40 degrees, whereas the normal animal, in the same situation, will localize a sound (buzzer) when the angle between separate positions in which it is presented successively is as small as 5 degrees.

From the post-operative study of the brains of animals used in some of the studies described above, and from studies done by Rose and Woolsey,[2] a fairly clear picture of the gross thalamo-cortical relationships has been obtained. After ablation of AI there is complete, or nearly complete, degeneration of the anterior half (approximately) of the principal part of the medial geniculate body. After ablation of AI, AII, and Ep the degeneration extends posteriorly to include the anterior two-thirds of the geniculate. Degeneration in the posterior part of the geniculate is found only when the ablation is extended into the insular and temporal cortex ventral to AII and Ep. In an unpublished anatomical study, Diamond, Chow, and Neff have shown that some degeneration of the posterior third of the medial geniculate occurs after experimental ablations confined to the insular-temporal region. From a careful analysis of the retrograde degeneration found in the medial geniculate after cortical ablation, it becomes clear that there is more than one kind of projection from the medial geniculate to the cortex. AI receives what Rose and Woolsey have termed "essential" projection, while AII, part of Ep, and the insular-temporal region receive "sustaining" projection; however, this two-category division is not sufficient, since it appears that the kind of projection to AII, Ep, and to the insular-temporal region may not be the same

Attention having been called to the insular-temporal cortex because of its anatomical relationship to the medial geniculate body, experiments have been started to determine the role it may play in auditory discrimination Results, which are not yet complete, indicate that frequency discriminations can be made after complete bilateral ablation of AI, AII, Ep, and the insular-temporal region (in some cases the ablations were also extended anteriorly in the ectosylvian gyrus to include somatic area II) A very surprising finding has been that a severe, and perhaps complete, loss of pattern discrimination occurs after bilateral ablation of the insular-temporal cortex alone, areas AI, AII, and Ep being left intact[18] This finding suggests that the insular-temporal region serves a function considerably more important than that of a receiving area for afferent impulses Its integrity may be essential for the normal functioning of the other auditory cortical areas, or it may have to do with the transmission and utilization of auditory information which is received and elaborated in areas I, II, and Ep A region homologous in terms of its relations anatomically to the auditory system and its role in auditory discrimination remains to be discovered in other mammals The identification of such a region in the monkey or other primate will be of particular interest

The cursory review which I have given of experimental studies of the auditory cortex is sufficient, I hope, to indicate that the so-called auditory cortex is not a unitary region, whether considered from the standpoint of its structural relationships or of its function We have a reasonable amount of knowledge about the afferent projections of the auditory system to the subdivisions of this region, we know very little, however, about its connections with other systems, *e g*, with the unspecific afferent systems, with the limbic system, and with the recurrent or efferent auditory system to which our attention has been called by the experiments of Grant Rasmussen[18 19 20]

In my opinion, we have made considerable progress in understanding something of the role of the total auditory region in sensory discrimination, but our analysis of the functions of the sub-areas is only beginning. This must be kept in mind when considering the relationship between the results of experimental studies and clinical studies of man. In the latter, complete bilateral destruction of auditory projection areas probably never occurs. Lesions produced by accident, disease or surgery are not likely to be confined to any one subdivision, nor even to auditory cortex, and the exact locus of the lesion can seldom be determined by post-mortem examination; nevertheless, if experimental studies of animals are extended in directions such as I have suggested, and, if use is made in the clinic of tests which measure functions similar to those which can be tested in lower animals, a gradual and profitable integration of findings from research in the experimental laboratory and in the clinic should be possible.

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# DISCUSSION OF FUNCTION OF AUDITORY CORTEX †

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## INTRODUCTION

A decade ago you would not have believed what has been presented today concerning the auditory system, and the auditory cortex in particular This modern research into the auditory system was initiated by the Office of Naval Research, to whom we owe a special debt for the contributions which you have heard Dewey Neff has presented an outstanding review of the research on the auditory cortex which presents many problems, and their solutions are slow in being realized Bit by bit the knowledge of the anatomy and physiology of the auditory cortex is accumulating, so that we have now a more advanced understanding of this region of the brain, however a serious need is a discipline which will permit a break through into the function of the auditory cortex, and more generally into the function of the brain as a whole We would like to hope that this discipline is attainable within the next decade The need for knowledge of how the brain functions is important, not only to the understanding of the relation of the auditory cortex to speech perception and hearing but also to an understanding of the brain in neurological and mental diseases I believe that you will agree with me after listening to these excellent papers today, that the audiometer after all tests but a tiny portion of our hearing

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†This investigation was performed under Contract Nonr-1779 (01) (NR 140-103) between the University of Oregon Medical School and the Office of Naval Research It was supported also by a research grant (B-45) from the National Institute of Neurological Diseases and Blindness Reproduction in whole or in part is permitted for any purpose of the United States Government

We are indebted for our knowledge of the minute anatomy of the nerve cells in the auditory cortex to Cajal[2] and Lorente de No,[3] who have applied the Golgi silver techniques to unravel the temporal region The nerve cells in the auditory cortex are so densely packed that the detailed course of the individual nerve connections cell by cell is still practically unattainable The nerve fibers from the medial geniculate body to the cortex have been explored grossly by retrograde degeneration techniques Some facts are known of the nerve fibers arising from the other parts of the brain and terminating in the auditory cortex Brodman's[1] parceling of the cerebral cortex into areas has proved of doubtful value to the modern neurophysiologist

Physiological studies have led to more precise location of the projections from the geniculate body upon the cortex, and in particular the detail within these connections [6 7 8 9 10 11] We have data on the time it requires nerve impulses to travel from ear to cortex, the distribution of responses over the surface, and the cell layers where the responses arise In ablation experiments performed on various animals we are faced with the surprising fact that surgical lesions of the auditory cortex produce little effect on conditioned reflexes [12] Removal of the auditory cortex causes no change in the threshold of hearing, multiple conditioned reflexes are not affected, but Dewey[15] has presented evidence for disturbances in conditioned reflexes to temporal aspects of stimuli The search for psychological correlates of hearing has been in vain Evidence for space localization of sounds, pitch discrimination or difference limens of intensity or pitch has not been found Perhaps there is some evidence for a loudness function

Thus far we have failed to implicate the auditory cortex with a specific function Let us consider more closely the meaning of function We all like to apply the term function in terms of our own behavior, or something that we can grasp simply Suppose in this case we consider the function in terms of the central nervous system With this in mind, let us examine certain stable properties of the auditory cortex that do not change under various conditions One such property is the frequency localization in which a response to a particular frequency of a sound always occurs in the same location[13] The spacing between the foci of response is constant, giving us what might be called a frequency map of the auditory cortex The time of arrival as well as the time course of the responses remain constant The masking of the cortical responses by means of steady tones or noise is extremely stable and accurately measureable[14] The masking data from the cortex are not unlike the results obtained in human subjects The threshold curve at the auditory cortex, even under anesthesia, is identical to the normal thresholds of human hearing Other constant properties are the refractory period, the absence of contralateral masking, the excitation of a strip of cortex at one intensity for one ear but not the other, and the refractory period between responses due to sounds delivered to the opposite ears

How the auditory cortex functions must be based upon the structural and physiological properties that remain stable The nervous system does not hear what is occurring at the ear, but only the electrical activity in the nerve cells of the pathways and the auditory cortex. It is a necessary premise that our acoustical environment must be represented in a reasonable form in the central nervous system, a conclusion not unlike that of Locke, Berkley and Hume, that our external world is limited to our own central nervous system Our interests in stable properties is that they alone can form the representations of the external environment The representations form a copy of the acoustical world, and it is with this copy that the nervous system must concern itself If the copy is not stable nothing would be known of the external world Since we are dealing with copies or representations, albeit in coded form, we are most certainly dealing with communication

In our study of these copies of our external environment, a region has been found in which after much simplification there exists a memory for over one-and-a-half billion different sounds,[15] a memory lasting as much as 200 times the duration of sound itself This portion of the auditory cortex is no longer than three-quarters inch and no wider than one-half inch Yet to this region of the brain no psychological correlate, nor function in terms of behavior, has been assignable

What then is the function of this area to the nervous system itself? What we would like to do is study the effects of the area on messages or information By studying the relation of acoustical signals to the representations it has become possible to establish a mathematical formulation of the communication aspects of the auditory cortex This allows up to compute the amount of information received at the auditory cortex in various sounds, therefore, might not communication theory be the discipline we need to understand the function of the brain? After all, the brain uses up more information than any other substance None of us would believe that the mind consists of mitochondria, proteins, sugars, acetylcholine, choline esterases or other enzymes These materials are like the junction of two metals to a transistor, or what oil is to a relay, but have no bearing on the information handled by such devices Needless to say the brain has been compared to computers, but in many ways it has properties different from these mechanisms I, therefore, ask you to watch the developments in information theory toward a solution of the problem of the brain

Study of the anatomy and physiology of the auditory cortex has uncovered a multitude of new facts during the last decade concerning its structure and performance Conditioned reflex studies have ruled out many possible functions of the area but have suggested other ones What is needed is a new discipline or scientific method which will give us the answer to the function of the brain Such a method we feel is very likely available in communication theory

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# FUNCTION OF THE AUDITORY CORTEX
## CLINICAL DISCUSSION (NEUROSURGERY)

ROBERT B KING,*
State University of New York,
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In discussing the functions of the auditory cortex from a clinical standpoint, a subject so ably presented by Dr Neff in "Parameters of controlled physiological investigation," I must confess that little definitive clinical work has been undertaken There are, however, many areas of mutual concern to physiologist, anatomist, physicist and physician, indeed, even surgeon As Dr Neff has said, there is often a 5 to 10 year gap between concepts of function demonstrated in laboratory environs and their initial adaptation for clinical use A major challenge to all of us must be to absorb this time deficit by earlier synthesis of laboratory analysis, and thereby to gain understanding of non-clinical investigative findings which are of clinical consequence Clinical perplexities, however, examined in the arena of the investigator, will yield fruitful avenues for investigation of fundamental mechanisms in anatomy, physiology and psychiatry The interchange of experience should be mutual

Recent and current studies of auditory cortex with parameters of neurophysiology and psychology have been discussed today Although clinical efforts to understand the functioning of auditory cortex in more than broad and general terms have had a late beginning, yet three avenues of clinical study are of current interest

Detailed examination of discrimination functions have been reported by Bocca, and were discussed in detail yesterday

In a similar vein, discriminative functions have also been studied in six patients with infantile hemiplegia before and after hemispherectomy

*1* Pure tone audiograms were normal A list of spondees was presented to each ear of these patients, and threshold intensity established for the correct identification of 50 per cent of these bisyllabic words. At 70 db above this threshold, then, two series of monosyllabic test words were delivered separately to each ear. A distinct discrepancy between the left and right was clearly evident in such testing of discriminatory function. Forty-five per cent of test words delivered to the ear contralateral to the abnormal hemisphere were incorrectly identified, while 20 per cent of the words so delivered to the ear contralateral to the more normal hemisphere were not repeated correctly. This 20 per cent may indicate a wide variation of normal related to the relatively normal hemisphere.

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Although the post op E.E.G. in this hemisphere became more normal, and there was improvement in seizures and behavior disorders in these patients, there was no improvement in their postoperative discrimination scores. This persisting deficit suggests that nociferous cortex of the abnormal hemisphere was not contributing materially to the deficit inferred for the more normal hemisphere. It may be that this degree of abnormality represents the maximum potential for discrimination of a single hemisphere. Further experience with such testing techniques as these may well yield useful methods for better clinical understanding of focal cortical lesions of auditory and related association cortex.

A second avenue of clinical investigation has been that which Penfield and his co-workers[2] have explored. The stimulation of abnormal cortex with patients under local anesthesia may initiate an auditory experience. Tinnitis may be reported with stimulation of the superior temporal gyrus. From neighboring regions, complex, and at times prolonged auditory sequences, songs or even symphonic orchestrations, may be reported by the patient. In this circumstance, however, a combination of memory and recall of auditory events add to the complexity of the analysis. Although the stimulus in such a circumstance as this is quite an artificial one, the experience described by patients may be realistic in many details.

There has been no extensive study of the electrophysiologic

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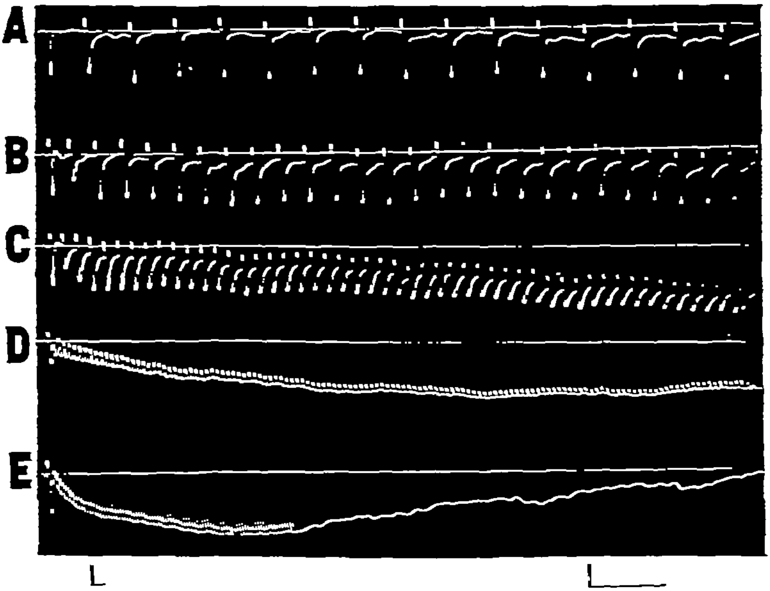

Fig. 2 Right angle at right calibration for E-500 V and 1 sec. Right angle at left is calibration for A-D 50 V and 20 msec.

Similar repetitive stimulation of subcortical white matter of the superior temporal gyrus (see Fig 3) shows further changes not seen in recordings from frontal association cortex. The increasing complexity of this response is apparent as the frequency of stimulation increases (B—6/sec., C—10/sec., D—20/sec., E—50/sec., F—100/sec.) In "B" and "C" a negative shift similar to that shown in Fig 2 for frontal association cortex is apparent, but in "D," "E," and "F," an early positive shift of the base is the dominant change returning to the original base line. The negative shift persists after the period of stimulation at lower frequencies potentials evoked by such stimuli in man A third avenue of investigation then is being explored Single and multiple evoked responses of human cortex are being studied and will be reported at a later date [3] Such evoked potentials indicate that there may be a number of regional variables in human cortex which do not appear in studies of other cortex

Fig 1 illustrates evoked potentials from human frontal association cortex and from the superior temporal gyrus A calomel cell recording electrode on the pia was recorded

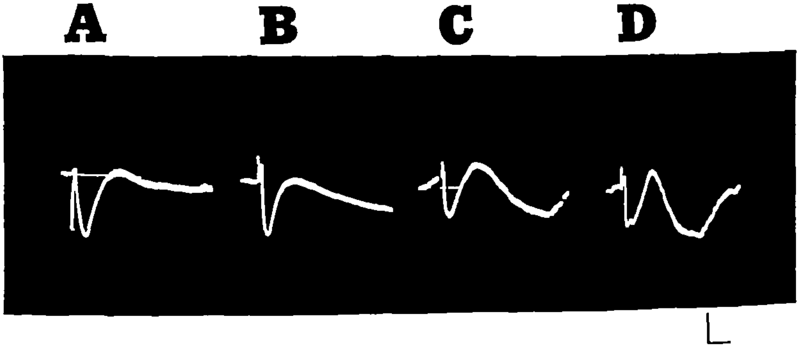

Fig 1 Calibration angle 500 V 20 msec

against a remote electrode Stimuli for "A" were delivered at the surface 3 mm from the recording electrode The potential indicates a pure dendritic response Stimuli for "B" were delivered at the subcortical white matter of the same gyrus just below the surface recording electrode (radiation response) In "C" the stimulus was applied to subcortical white matter of the adjacent gyrus activating "U" fibers The surface of the superior temporal gyrus was recorded in "D," while stimulating adjacent white matter (radiation response) The response in "B" and "D" are then analogous The increased complexity of the potential form in the later instance is apparent The prolonged late negative deflection in "D" has not been seen in records taken from a limited number of other cortical regions

Further comparison of the evoked cortical response in frontal and temporal association areas can be illustrated in the next two slides The first (see Fig 2) illustrates evoked radiation responses from frontal association cortex (as in Fig 1B) with repetitive stimulation (A—6/sec , B—10/sec , C—20/sec , D—50/sec , and E—50/sec ) using DC amplifiers Note the negative shift in steady potential with increasing frequency of stimuli, and the persistence of this shift after terminating the stimulus

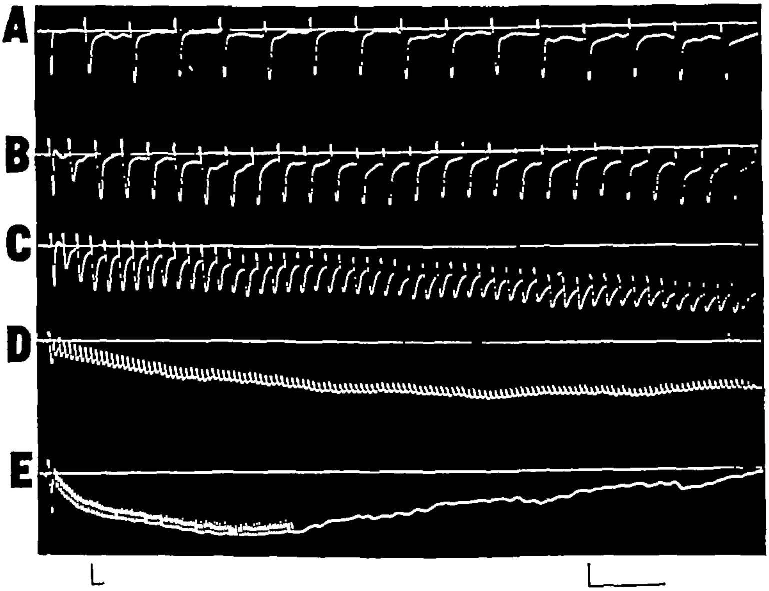

Fig 2 Right angle at right calibration for E 500, V and 1 sec Right angle at left is calibration for A D 50 V and 20 msec

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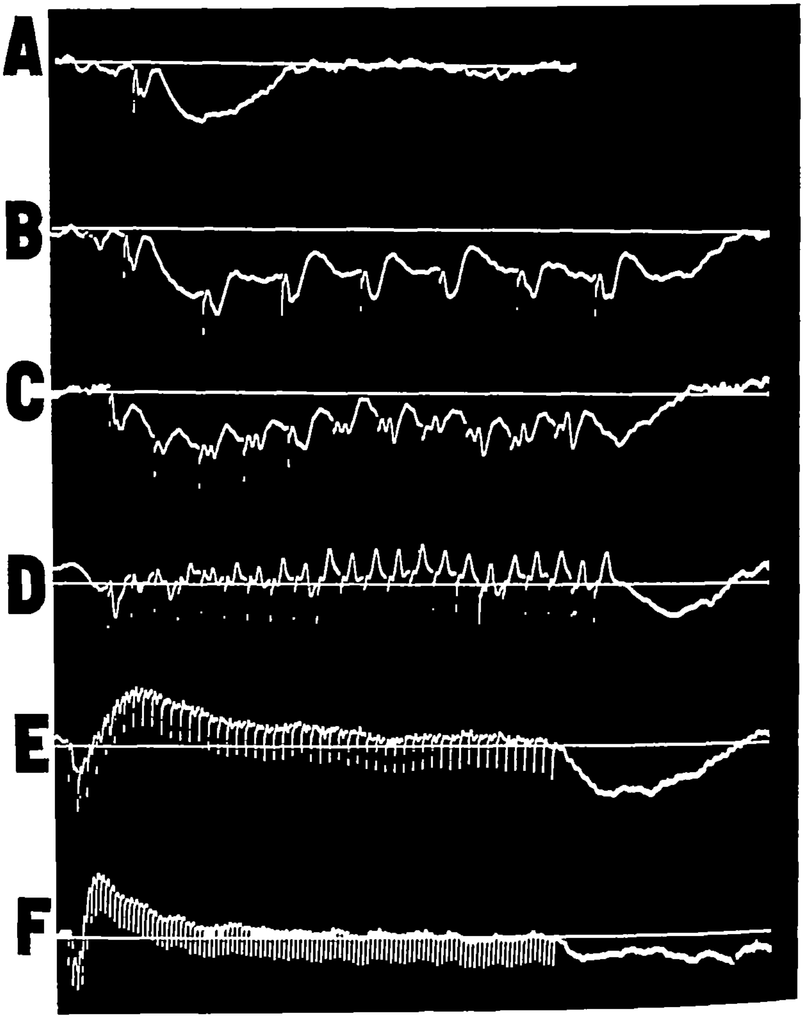

Fig 3 Vertical celibration 500 V Horizontal calibration 20 msec

A detailed analysis of these evoked cortical potentials is not warranted at present Many more records must be acquired before a synthesis, based on such an analysis, can have meaning in terms of the functioning of neural components of frontal and temporal association cortex This third avenue of clinical investigation has only recently been followed and must be further explored

In summary, I have tried to indicate three avenues for clinical investigation of the functioning of auditory cortex which have shown some promise of extending our knowledge of these regions

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# PERCEPTIVE HEARING LOSS *

Harold F Schuknecht,

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In recent years much investigation has been directed toward the physical and bioelectric mechanisms by which the cochlea receives the sound stimulus and codes it into neural impulses Our knowledge of the auditory physiology beyond the cochlea is less well known Future research in this area will be concerned with the mechanisms by which neural patterns are decoded and integrated with established memory patterns and other information, to result in hearing as we experience it

## THE HUMAN AUDITORY CORTEX

The human cerebral cortex has been mapped according to minor variations in the pattern of the grey matter[1,2,3] The auditory cortex of man is located in the superior temporal gyrus along the sylvian fissure, which corresponds to the topographic areas 41, 42 and 22 of Brodmann (see Fig 1)

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*Perceptive hearing loss here refers to that type due to disorders of the auditory pathways and cortex which is in accordance with the recent terminology suggested by the Committee for Conservation of Hearing of the American Academy of Ophthalmology and Otolaryngology

Campbell has further divided this area into an audito-sensory region (area 41, thought to be related mainly to auditory perception) and an audito-psychic region (areas 42 and 22, thought to be important for auditory memory) These concepts, however, do not justify thinking of these areas as discrete functional units

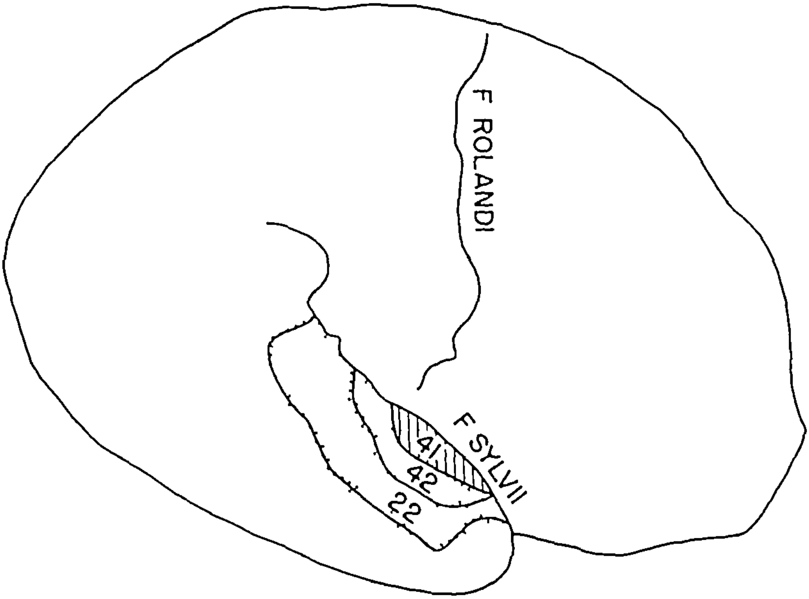

Fig 1 Auditory cortex of man as determined by cyto-architectonic studies Shown are areas 41 42 and 22 of Brodmann and the audito-sensory (ruled) and audito-psychic (stippled) areas of Campbell

Further evidence regarding the auditory cortex of man comes from the investigations of Penfield and Rasmussen,[4] who electrically stimulated the auditory cortex of humans during the course of intracranial operations Local anesthesia was used, and the patients were asked to relate their auditory experiences

Some of the sensations reported by the patients are listed below

Ringing sound like doorbell
Humming sound
Low-pitched sound like a motor

Continuous "clicking," like crickets at night
Change in the sound of your voice
Rushing sound, like a bird flying
Contralateral ear felt as though she could not hear out of it
Noise like birds chirping
I hear funny things
I hear "boom boom" on something
Buzzing in contralateral ear
Key of your voice changed
I am a little deaf

The records from these patients did not lend themselves to statistical study or detailed analysis, however, the investigators made the following observations

*1* *Auditory responses were more numerous in the audito-* psychic area of Campbell (areas 42 and 22 of Brodmann), and less frequent in the audito-sensory area (area 41 of Brodmann)

*2* Electrical stimulation of the temporal lobe resulted in the sensation of sound in some patients and the sensation of being deaf in others, therefore, stimulation seemed to paralyze as well as activate

*3* The auditory sensations were most often referred to the contralateral ear

*4* Electrical stimulation close to the margins of the sylvian fissure were more apt to produce simple tones, ringing, etc, while stimulation away from the fissure was more apt to introduce an element of interpretation of the sound

They also made a very interesting observation in patients having psychical seizures, the latter being described as a purely psychical state characterized by sudden change in perception of environment, a sort of dream state Several patients having visual or auditory hallucinations in their psychic state experienced these phenomena when the temporal cortex was electrically stimulated Apparently in these patients the cortex previously had been activated or conditioned by recurrent epileptic discharges, so that electrical stimulation resulted in activation of acquired patterns of neural flow, in other words, the memory pathways

## LESIONS OF THE TEMPORAL LOBE

The possible effect of unilateral temporal lobe tumors on hearing has interested clinicians for some time, but because hearing tests were lacking in quantitative values no consistent pattern of auditory loss was established for temporal lobe lesions [5,6-8] Although bilateral temporal lobe lesions are less common, they can exist in Pick's disease and in cerebrovascular disorders, and in such cases the observers have consistently reported a total bilateral hearing loss [6,9,10,11] With the development of electronic equipment, which permitted standardized audiometric evaluations, many new psychoacoustic phenomena have become manifest One of the phenomena pertinent to this discussion only recently established is the loss of auditory intelligibility which accompanies temporal lobe tumor This observation was slow in developing because the discrimination defect did not register in commonly used discrimination tests but became manifest only when a more difficult test was imposed upon the auditory system

Apparently the amount of auditory information which is provided with each phoneme in normal speech is in excess to that which is necessary for intelligibility and, therefore, mild degrees of receptive aphasia (loss of auditory intelligibility) can exist without being detected by standard discrimination tests Bocca, et al ,[12] and Pietrantoni, et al ,[13] have shown, however, that if a patient with a temporal lobe tumor is given a more difficult discrimination test, consisting of distorted speech (accelerating, interrupting, limiting frequency range, delivering in noise), the intelligibility is decreased in the ear contralateral to the temporal lobe lesion Goldstein, et al ,[14] also have observed this phenomenon in patients with infantile hemiplegia

Patients so afflicted are unable to understand the spoken language in spite of normal auditory acuity Sounds reaching the ears of these patients are transmitted along the auditory pathways, but have no meaning Perceptive aphasia appears to be a true entity and is thought to result from aplasia, mal-development or trauma to the auditory cortex. Further proof is needed, however, to establish firmly the concept that auditory aphasia is the manifestation of a temporal lobe cortical deficit. A similar disorder, termed auditory imperception, is characterized by an ability to understand speech and develop language with auditory training, but difficulty in interpreting auditory tests involving discriminatory responses.[15] Derbyshire, et al.,[16] have shown that under favorable conditions auditory responses can be recorded in electroencephalograms of humans, and that the method can be used as an objective test of hearing. According to Rosenblith[17] it may be possible to develop that method into a practical clinical tool through the use of an electronic computer, which will sift the auditory response out of random background cortical activity. A serious limitation of objective auditory tests, of course, is that they do not tell us whether the responses reflect useful organized auditory information.

## DECREASE IN NEURONE POPULATION

Neff and associates[18] have shown that after bilateral ablation of the auditory cortex in cats, the pure-tone threshold is preserved, but more complicated discriminations, such as localization of sound and pitch discrimination, appear to be altered. The combination of circumstances in which there is a discrimination loss out of proportion to the change in pure-tone thresholds is not unique for cortical lesions, for it is also present when the first order neurone is partially destroyed by acoustic neurinoma, as was first pointed out by Woellner and myself in 1953,[19] and subsequently by Liden[20] and Walsh and Goodman[21] and Goodman.[22] (see Fig. 2).

The deafness of aging (presbycusis) also is often characterized by discrimination loss out of proportion to the pure-tone threshold loss (see Fig. 3). It has already been shown that the presbycusic ear often suffers greater degeneration of the cochlear nerve than of the corresponding organ of Corti[23, 24, 25] (see Fig. 4). In the aged person the neurone population at higher levels in the auditory system may also be decreased,

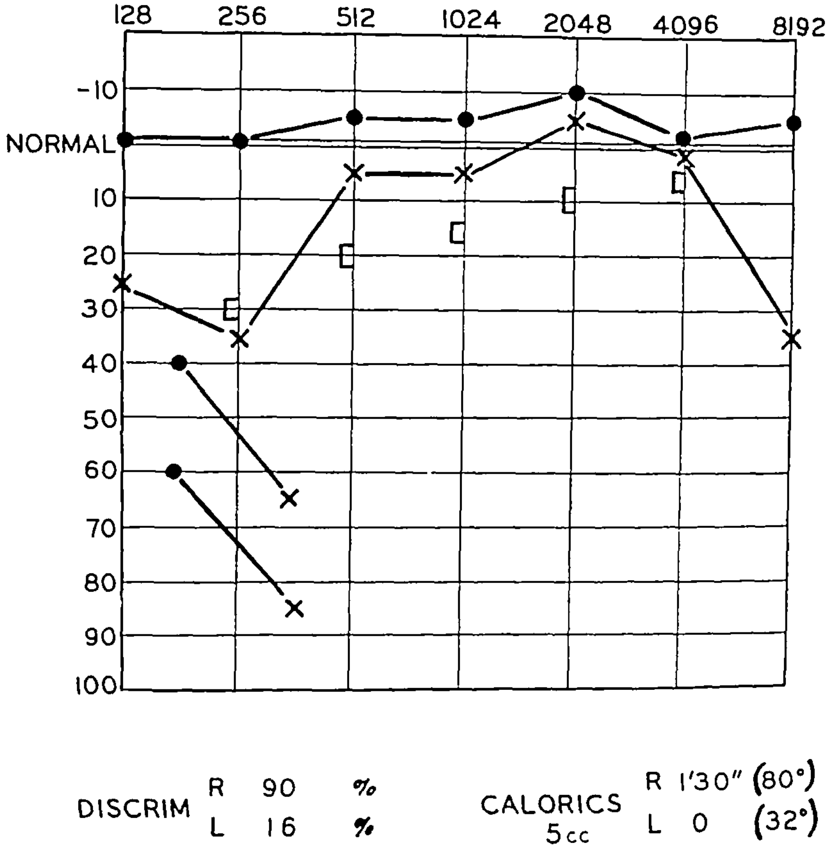

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Fig 2 Audiometric and vestibular tests of patient with left acoustic neurinoma proven subsequently at operation In the left ear the pure-tone thresholds for the three speech frequencies (500 1000 and 2000) were near normal however the speech discrimination score was only 16 per cent on repeated tests (PB-Max Rush Hughes recorded word list)

for it is well established that the aging brain suffers a diffuse neuronal degeneration

The auditory manifestations in patients with temporal lobe lesions, acoustic neurinoma and presbycusis, suggest that lesions involving the auditory pathways result in a system that transmits simple signals of threshold magnitude (such as pure tones) but cannot handle the complex signals of speech

Woellner and I designed an experiment in which we further tested the concept that partial loss of fibers at the level of

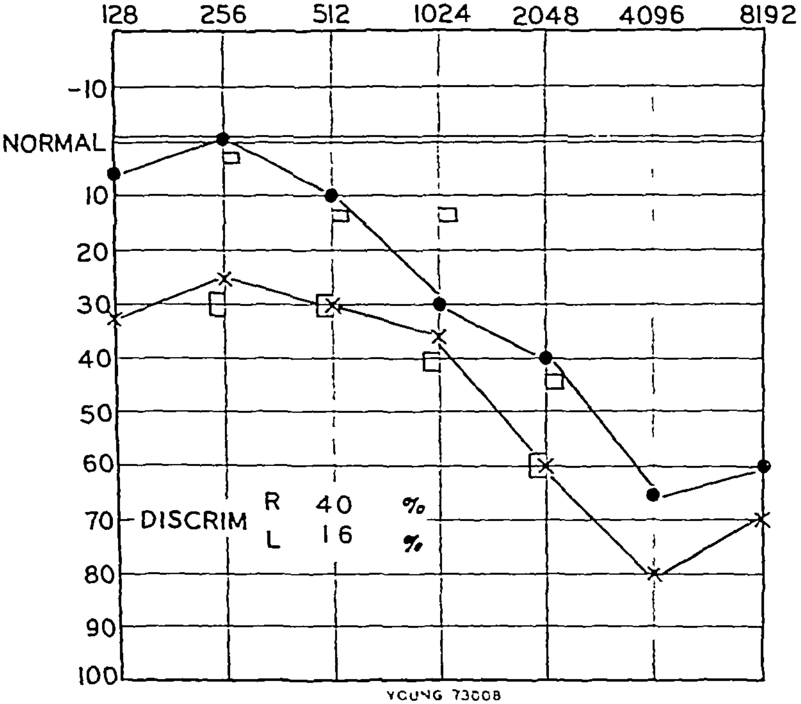
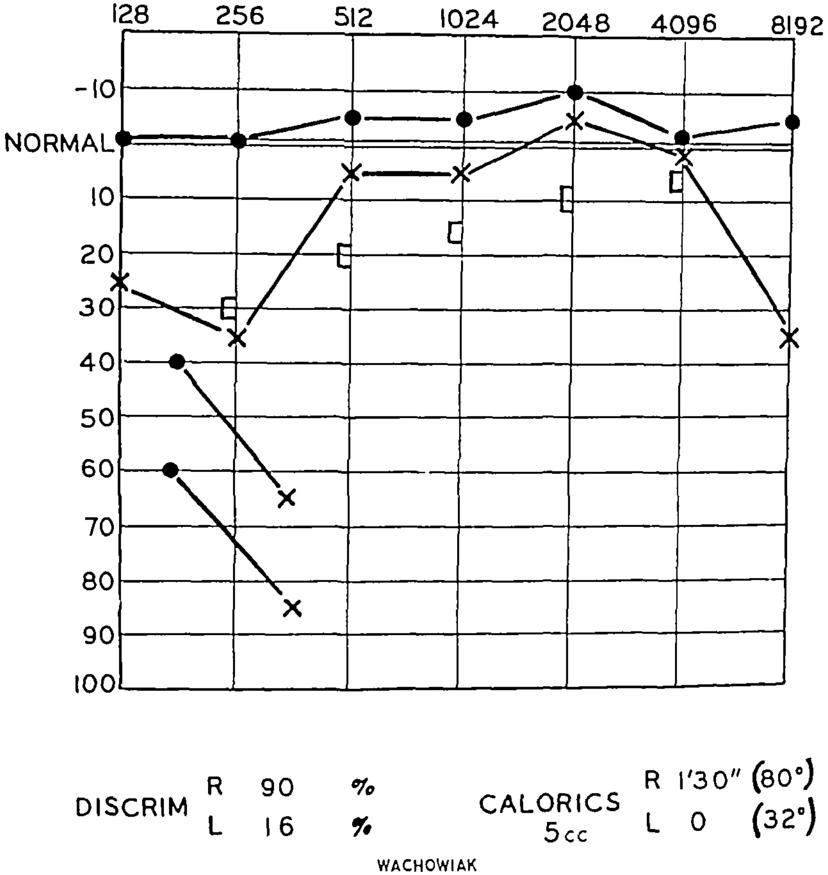


Fig 3 Audiometric findings of 70-year-old man with presbycusis showing discrimination loss out of proportion to loss for pure tones (PB-Max live monitored voice)

the first order neurone is consistent with normal pure-tone thresholds Working with conditioned cats we found that 75 per cent of the acoustic nerve fibers could be lost by actual count without creating a hearing loss for pure tones[26] (see Fig 5)

## COMMUNICATION THEORY

In recent years concepts of information-transmission have been expressed in precise mathematical terms Although few of us are capable of understanding the mathematics involved, we readily appreciate its importance for auditory intelligibility, the ear analyses speech by recoding the sound signals into impulses which travel up the auditory nerve We know that the fundamental coding mechanism is very simple, and that a nerve impulse is either present or absent



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This principle of "all or none" is basic to nerve physiology Other limitations are that a single nerve fiber will carry a maximum of only 800 to 1000 impulses per second We may enumerate the variables in a neurone pattern as follows *1* Frequency of impulses in a single fiber (below 1000 c p s ) , *2* time relation between impulses in the various fibers, *3* selectivity as to which fibers are being activated, *4* the number of fibers being activated In spite of the "all or none" law, the cochlear nerve can carry all of the information required for intelligibility of the spoken voice This is possible because of the tremendous number of channels in this communication system, for we know there are about 35,000 channels, or fibers, in the human cochlear nerve In a pathological auditory pathway with a loss of nerve fibers, a limitation is imposed upon the coding mechanism, and the amount of information which can be transmitted from the ear to the brain is less than normal

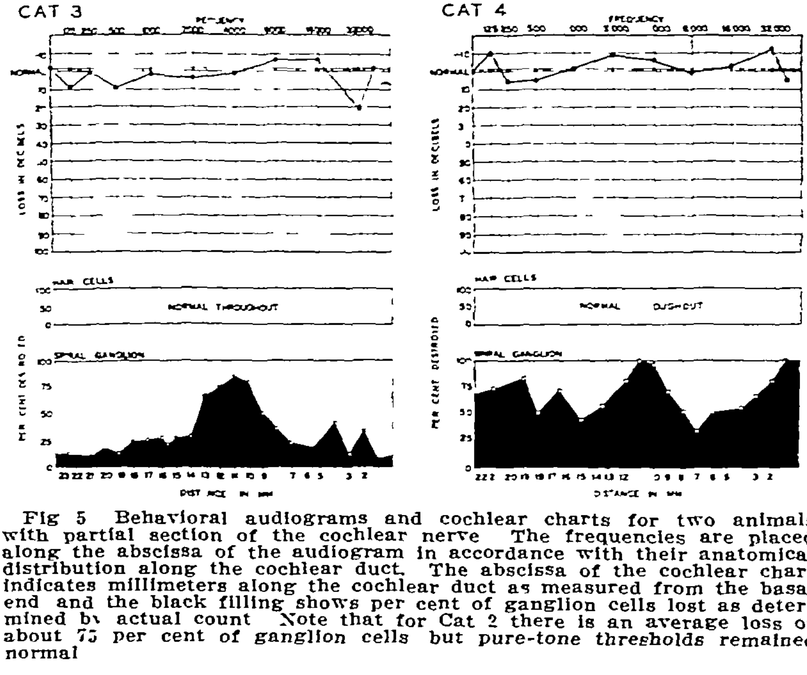

Fig 5 Behavioral audiograms and cochlear charts for two animals with partial section of the cochlear nerve The frequencies are placed along the abscissa of the audiogram in accordance with their anatomical distribution along the cochlear duct. The abscissa of the cochlear chart indicates millimeters along the cochlear duct as measured from the basal end and the black filling shows per cent of ganglion cells lost as determined by actual count Note that for Cat 2 there is an average loss of about 75 per cent of ganglion cells but pure-tone thresholds remained normal

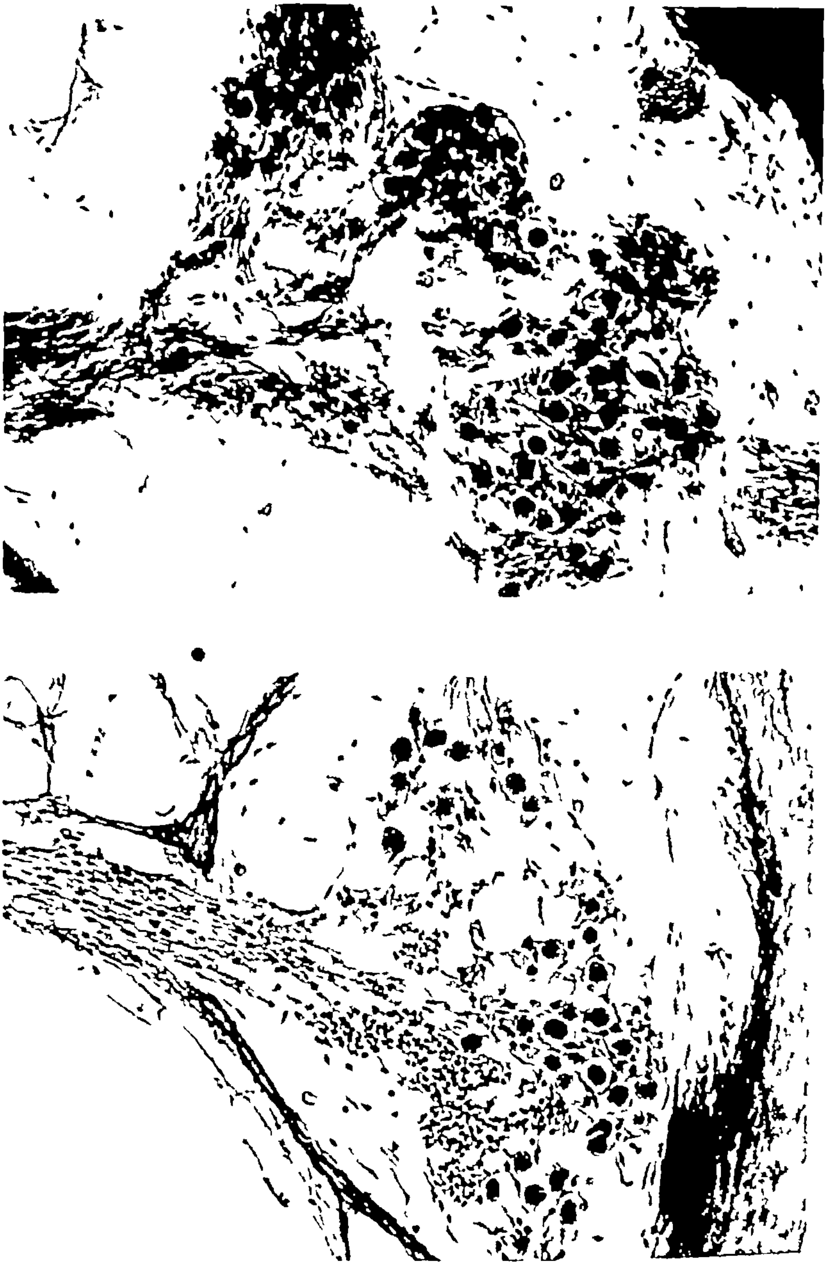

Fig 4 Photomicrographs of spiral ganglion of normal young person (above) and 70-year-old man (below) both views from the upper basal turn The aged man had severe degeneration of the organ of Corti and spiral ganglion in the lower basal turn accounting for a high tone deafness In the upper basal turn the organ of Corti was normal but there was a loss of 30 per cent to 50 per cent of the spiral ganglia It is this loss of neurone population which probably accounts for the deteriorating auditory discrimination (phonemic regression) in the aged

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## CONCLUSIONS

No one has yet evolved a completely clear concept of the psycho-acoustic manifestations resulting from lesions of the auditory pathways and centers  It is already apparent, however, that such lesions result in losses of intelligibility, varying from the mildest, detected only by special discrimination tests, to severe auditory aphasia  I am certain, however, that further physiological experimentation and clinical study will provide a better basis for the regional and functional diagnosis of disorders involving the auditory pathways

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## CONCLUSIONS

No one has yet evolved a completely clear concept of the psycho-acoustic manifestations resulting from lesions of the auditory pathways and centers It is already apparent, however, that such lesions result in losses of intelligibility, varying from the mildest, detected only by special discrimination tests, to severe auditory aphasia I am certain, however, that further physiological experimentation and clinical study will provide a better basis for the regional and functional diagnosis of disorders involving the auditory pathways

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ancient method now, but it was a popular technique then About 1930 the first sound level meters were introduced Because the users soon found that many sounds gave the same reading on the meters but did not sound the same, an effort was made to approximate the characteristics of the ear This effort was unsuccessful, but the results of it remain with us as the A, B, and C scales of modern instruments

It soon became clear that some sort of frequency analysis was necessary Various narrow-band analyzers were developed, but their use was limited because of the tedious nature of the measurement The more modern octave band analyzer strikes a happy medium between detailed frequency analysis and ease of measurement It has been used extensively in the past decade, and most industrial noise data are today being reported in octave bands Recently, fractional octave bands have appeared but do not, to date, enjoy widespread use because of the added complexity of reporting the data

Until a few years ago sound pressure level and frequency were the primary parameters involved in noise measurement All measurements were essentially cross-sections in time Very little attention was paid to the fluctuations and variations of the noise as time passed An excellent compilation of industrial noise measurements of this type has been prepared by Karplus and Bonvallet, (*American Industrial Hygiene Association Quarterly,* Vol 14, page 235, 1953), however, measurements of this sort can only be related to impairment of hearing when the exposure is steady throughout the working day, and the noise has no unusual transient characteristics

Since the relations of noise to hearing loss are of great importance in the field of industrial noise, more emphasis has been placed in recent years upon the design of instruments that give information about the transient character of the noises The impact meter, developed by General Radio, and the exposure meter, developed by Crouch, are two examples of this trend toward instruments that are aimed at the measurement of the time-varying characteristics of noise Research sponsored by the Armed Forces has also been di-

# THURSDAY MORNING SESSION,

May 16, 1957

## HEARING LOSS AND NOISE EXPOSURE

The International Conference on Audiology convened at 9 30 A M , in the Auditorium of the Washington University School of Medicine, St Louis, Missouri, Prof Walter A Rosenblith, Associate Professor of Communications Biophysics, Massachusetts Institute of Technology, Cambridge, Massachusetts, presiding

DR IRA J HIRSH, (St Louis, Missouri) Unfortunately, Dr Kenneth Day could not be with us, and Prof Walter A Rosenblith has consented to act as chairman for this session

## NOISE IN INDUSTRY

JEROME R COX, JR ,

Central Institute for the Deaf,

St Louis, Missouri

This is a report on some noise measurements that were made in a number of factories in a certain section of the United States These measurements were directed towards evaluating individual noise exposures The goal of the survey was some statistical indication of the industrial noise exposures in a section of the country Before presenting the procedure for the survey and the results, I will give a brief review of noise measurements in the United States

In 1925, noise measurements were made in the City of New York, with the aid of the 3-A audiometer, an early Western Electric instrument The masking produced by the noise was measured by the audiometer The sound pressure levels were then calculated from the masking This seems like an

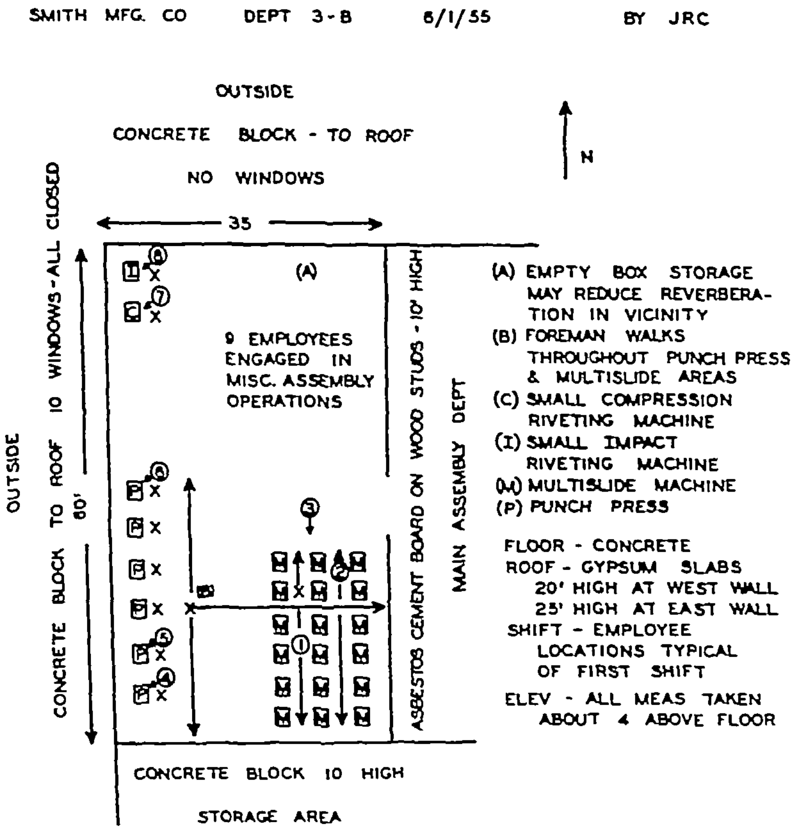

SMITH MFG. CO
DEPT 3-B
6/1/55
BY JRC
OUTSIDE
CONCRETE BLOCK - TO ROOF
NO WINDOWS
N
35
80'
OUTSIDE
CONCRETE BLOCK TO ROOF 10 WINDOWS - ALL CLOSED
ASBESTOS CEMENT BOARD ON WOOD STUDS - 10' HIGH
MAIN ASSEMBLY DEPT
(A)
9 EMPLOYEES ENGAGED IN MISC. ASSEMBLY OPERATIONS
(A) EMPTY BOX STORAGE MAY REDUCE REVERBERATION IN VICINITY
(B) FOREMAN WALKS THROUGHOUT PUNCH PRESS & MULTISLIDE AREAS
(C) SMALL COMPRESSION RIVETING MACHINE
(I) SMALL IMPACT RIVETING MACHINE
(M) MULTISLIDE MACHINE
(P) PUNCH PRESS
FLOOR - CONCRETE
ROOF - GYPSUM SLABS 20' HIGH AT WEST WALL 25' HIGH AT EAST WALL
SHIFT - EMPLOYEE LOCATIONS TYPICAL OF FIRST SHIFT
ELEV - ALL MEAS TAKEN ABOUT 4 ABOVE FLOOR
CONCRETE BLOCK 10 HIGH
STORAGE AREA
①
②
③
④
⑤
⑥
⑦
⑧

Fig 1 Typical floor plan of department surveyed All significant noise sources in this small shop are identified working areas of employees are indicated by crosses and each measuring station is marked by a circled number

industry and the number of employees, shifts, breaks in the daily exposure, and other departmental information The fundamental framework for reporting our data is shown in Fig 1

This is a drawing typical of the departments surveyed This is the floor plan of a small shop, showing all the significant noise sources, the location of all the workers, the location of each of the measuring stations, and, in addition, information about the acoustical environment and movements of employees who do not remain in a fixed position rected toward the measurement of noise exposure rather than the simple frequency distribution that was so popular during the past decade

I think the concept of a noise exposure is one of the important developments in the field of industrial noise It is usually assumed that time and intensity are equally important in determining the noise exposure A quantitative way to state this assumption is to say that sound energy, the product of time and intensity, is proportional to the noise exposure, and, therefore, directly related to the hearing loss that may result from the exposure Students of physics will recall that the product of time and intensity is energy—in this case sound energy

In computing sound energy, intensity is expressed in watts per unit area rather than in decibels, a logarithmic unit Translated into decibels, the energy rule means that a noise present throughout an eight-hour working day would be equivalent to a similar noise that is present during one-half the working day, but three decibels more intense Similarly, a noise present only one-tenth of the working day is equivalent to a noise ten decibels less intense, but present throughout the working day The assumption that noise exposure is proportional to the sound energy received by the ear has not been adequately validated It is a frequent assumption, and I will make no attempt to justify it

In order to evaluate noise exposure a tremendous amount of data is necessary It is almost unbelievable to people who have not encountered the problem Data must be taken on the intensity, frequency distribution, transient characteristics, and the daily time pattern of the noise In addition, the workers' movements in the noisy area, and the characteristics of the sound field, must be recorded With these data, it is possible to estimate the noise exposure according to the assumption that exposure is proportional to sound energy In the measurements to be reported, we attempted to gather all of the information necessary for the evaluation of every man's noise exposure in each of the plants surveyed

A general data sheet gave information about the kind of was studied The total number of workers whose exposures were evaluated is just slightly under thirty thousand As you can well imagine, considerable data was accumulated

Because of the scope of the survey, it was necessary that a simple scheme be developed for analysis of the data The following procedure was followed *1* A rough frequency analysis was carried out to estimate the sound pressure level in the 300-600 c p s band This octave was chosen because it is the important sorting octave, according to the data presented in the report of Committee Z 24-X-2 of the American Standards Association (American Standards Association, *The Relations of Hearing Loss to Noise Exposure,* Z 24-X-2 Report New York, 1954) *2* The equivalent exposure level was found by using the assumption that energy is proportional to exposure discussed a few moments ago *3* Appropriate adjustments based on experience with similar machines in other plants must be employed, because quite often data are not as complete as they should be. *4* All of the noise exposures are categorized into the four classifications shown in Fig 3

| Classification of Noise Exposure | A | B | C | D |
|---|---|---|---|---|
| Equivalent Sound Pressure Level in the 300 600 c p s Octave Band | Greater Than 105 db | 105 db to 95 db | 95 db to 85 db | Less Than 85 db |

Fig 3 Classification of noise exposures according to the steady sound pressure level having a total energy each day equal to that in the 300-600 c p s octave of the actual noise

The equivalent sound pressure level shown is in the 300-600 c.p s octave band All of the noise exposures are sorted into these four classifications After obtaining the totals in each classification we were surprised to find fewer A exposures than anticipated Upon re-examining the distribution of industries in the area studied we find a heavy representation of industries having only a few A exposures, therefore, an adjustment of each of the major classifications of industry was made on the basis of the census of manufacturers

Noise measurements were sometimes made with octave bands, but often a simple sound survey meter sufficed because it is faster, less conspicuous, and satisfactory for rough evaluations of noise exposures A rough frequency analysis can be made from readings taken on the three scales, A, B, and C, of the survey meter (J R Cox, Jr , Approximate frequency analysis from weighting-network data in acoustic measurements *General Radio Experimenter*, Vol 28, p 1, 1953) This scheme worked because of the statistical nature of the survey, but cannot be generally recommended

| Location No | Meter Readings (db ) A | B | C | REMARKS |
|---|---|---|---|---|
| 8 | 98 | 98 | 98 | 1 A small riveting machine Connector is held on anvil and hammer sets rivet Repeated impact<br>2 About 300 blows/min Operator makes 12 parts/min<br>3 Sound of hammer striking small part No other source of noise<br>4 Each rivet takes 5 10 sec 4 bursts/part Machine in use when compression riveting is behind schedule Foreman estimates that this occurs about 25% of the time Operator is otherwise unexposed |

Fig 2 A small section of the form used to report data from each of the measurements stations The four items at the right describe the noisy machine its operating conditions the nature of the noise and the noise exposure pattern The number at the left refers to the location of the measurement shown on Fig 1

Figure 2 shows a small section of the form used to report data from each measurement station At the right we see four items the nature of the noisy machine, the operating conditions of the machine, the nature of the noise from the machine in terms of some more familiar noise, and the noise exposure pattern In this example the machine is on only about twenty-five per cent of the time

The survey covered a total of seventy-five plants in twelve different classifications used by the Census Bureau Of the remaining eight, several were not noisy industries, some employ very few people, and one was not found in the area in which this survey was conducted, therefore, it is believed that a sufficiently large variety of noisy industries nation subjected to A exposures were suddenly to incur a 50 db hearing loss, the mean threshold hearing level of the nation would shift by only 0 2 db This verifies the fact that there must be many other causes of hearing loss There are others not considered in this study who have serious noise exposures Many people use firearms extensively in and out of the Armed Services In addition, there are other kinds of hearing losses that are difficult to differentiate from hearing loss caused by noise

One final statement that deserves emphasis is just because a man works in industry is not a sufficient reason to assume that his hearing loss is caused by noise

## HEARING LOSS IN INDUSTRY

Aram Glorig,
William Grings,
Anne Summerfield,

Subcommittee on Noise in Industry,

Los Angeles, Calif

### INTRODUCTION

Valid information about the relations of hearing loss to noise-exposure is difficult to obtain Undoubtedly, this difficulty is due in part to the complexity of the relations, but there are also many obstacles that must be overcome before we can obtain suitable data from which to draw valid conclusions about these complex relations It is the purpose of this paper to discuss a recent study of industrial hearing loss as a means of showing some of the difficulties encountered in making inferences from existing audiometric records, to discuss the difficulties generally encountered in field research in hearing, and to describe our attempts to lessen these difficulties

Two important questions to be answered are *1* How much hearing loss results from noise-exposure, *2* what is the rela-

The total number of workers in noisy industries is shown in Fig 4 The population of the nation at the time of the survey was a hundred and sixty million The total number of people not in schools or hospitals is one hundred and ten million The labor force is sixty-three million, but the labor force in the manufacturing industries is only seventeen million Excluding administrative workers the remainder is fourteen million, of whom only ten million are in industries that have significant noise exposures It is estimated that those ten million workers are distributed among the noise exposures A, B, C, and D, according to the percentages shown in Fig 5

| | Millions |
|---|---|
| U S Population (1953) | 160 |
| Non Institutional Population | 110 |
| Labor Force | 63 |
| Labor Force in Manufacturing | 17 |
| Production Workers in Manufacturing | 14 |
| Production Workers in Noisy Industries | 10 |

Fig 4 Distribution of the U S population at the time of the survey Noisy industries exclude those that generally have no significant noise exposures anywhere in the industry i e the apparel industry

PERCENTAGE OF PRODUCTION WORKERS IN NOISY INDUSTRY IN VARIOUS NOISE EXPOSURE CLASSIFICATIONS

| | A | B | C | D |
|---|---|---|---|---|
| *Percentage* | 0 5% | 4 5% | 17% | 78% |

Fig 5 Estimate of the percentage of workers in noisy industries who are exposed to various noise exposure classifications as defined in Fig 3 Percentages are adjusted from regional survey data to reflect national distribution of noise exposures The Armed Services transportation and construction workers and farmers have been excluded from the survey

One is surprised that the percentage in the A classification is so small Remember, however, that the Armed Services, transportation and construction workers, and farmers have been excluded from the study Only workers in manufacturing industries that have significant noise exposures have been included

In conclusion, there are a few severe noise exposures, but many less severe ones, in fact, if all of the workers in the

The data sampled contains 9,145 audiograms of industrial and flight line personnel The audiograms represented 5,816 different individuals—3,212 factory workers and 2,604 flight line personnel There were 3,229 repeat audiograms The repeat audiograms included both periodic recheck and special medical referrals, and it was not possible from the record to differentiate between these two

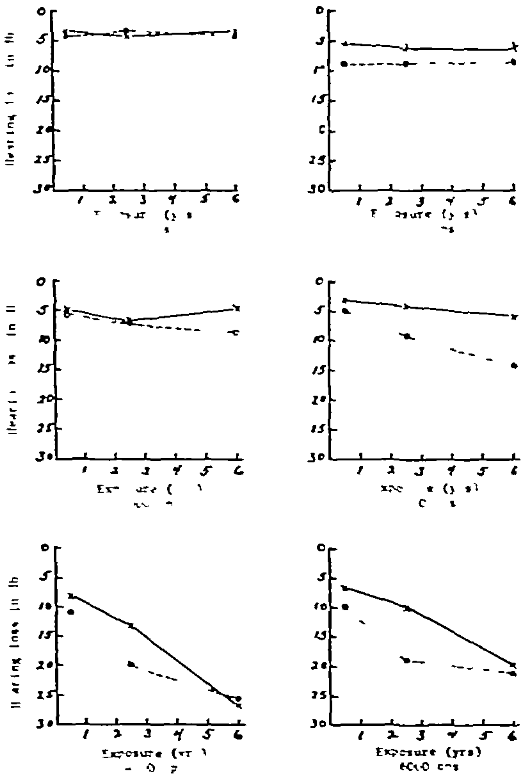
Supplementary information provided with the audiograms included age, history of exposure to noise, job category and medical history Age was indicated by groups of years only, 18-25 years, 26-35 years, 36-45 years and 46 years or over Exposure to factory noise was recorded in three classes less than one year, 1-5 years and 5 years and over Flight line (jet) exposure time was specified in hours 0-100, 100-500, and 500 hours or over Most persons had work experience in more than one job category The largest "pure" work group, 1,196, was made up of riveters Accurate serial records of noise-exposure factors and of information about changes in medical or work history were not always available

The data contained evidence of the production of hearing loss by noise-exposure Fig 1 shows curves of hearing loss vs years of noise-exposure for groups of male factory workers Separate curves are presented for each of three age groups 18-25, 26-35 and 36-45 years Note that the curves show increasing high frequency hearing loss with increasing exposure time At frequencies below 2000 c.p s there is less evidence of systematic change Hearing loss as a function of years of exposure for 1,190 riveters is plotted in Fig 2 According to the information available in the records, these men had been exposed to riveting noise only Note that the hearing losses shown by these men are very similar to the losses displayed in Fig 1, which represents the entire group of factory workers Tests of statistical significance were applied to these data, and the results indicate that hearing losses at frequencies above 3000 c p s are statistically significant At 3000 c p s, losses in the older age group only are statistically significant, and below 3000 c p s the indicated losses are statistically not significant From these results we would infer that on the average, as the years in noise increase so tive importance of different conditions that contribute to the production of hearing loss? To answer these questions we must have measurements of many noise-exposures and serial audiograms of persons exposed to each noise, serial audiograms consist of an original and several well spaced repeat audiograms The audiometric measurements must be accurate, and the information contained in the description of the noise-exposure must be complete and detailed

The ideal approach to the problem of hearing loss in industry would be to carry out controlled experiments in industrial plants For these experiments we would require ideal testing environments and complete freedom for scheduling tests We would test many persons at repeated intervals of various lengths Different groups of these persons would be exposed to noise of different specific characteristics, and there would be no overlapping of the specific exposures Obviously, practical considerations limit the achievement of such ideal experimental conditions in the field It has been possible, through the generous cooperation of certain companies, to do controlled experiments in the field with small numbers of persons, but for some of the statistical analyses we wish to perform we need many thousands of audiograms It is not possible to collect this special data from large groups of persons in the field We are restricted to the information we can obtain from the data records that are made available to us from hearing conservation programs already organized and carried out in industry As a specific illustration of this type of data analysis, let me describe a recent study made at the Research Center of the Subcommittee on Noise in Industry

## RECENT STUDY OF INDUSTRIAL HEARING LOSS

The raw data for this study were obtained from records which had been made available by a large aircraft manufacturer These data were entered on punched cards and were then analyzed with respect to three topics *1* Evidence for hearing loss caused by noise-exposure, *2* differences in hearing loss occurring in different plant occupations within the company, and *3* possible sources of error which might invalidate the results of the study



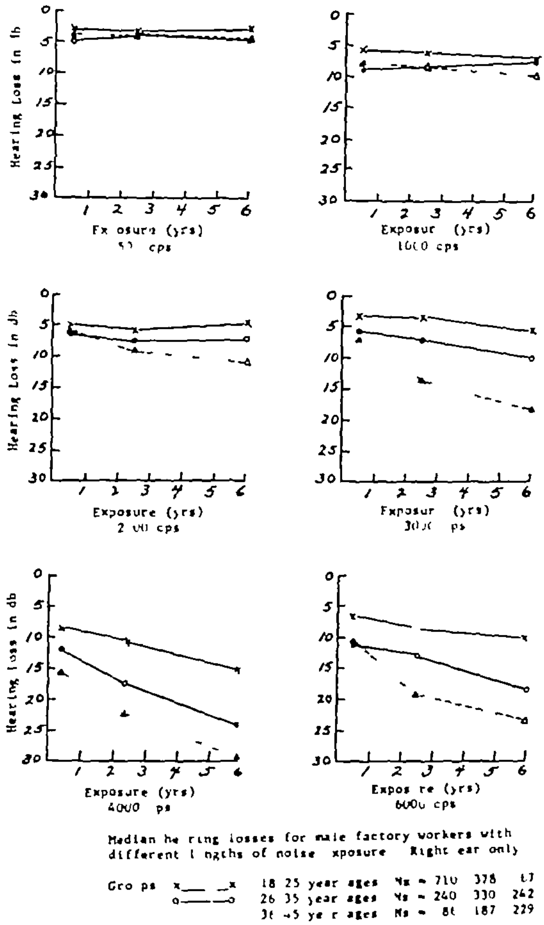
Median [illegible] loss [illegible] 19 workers with riveting experience [illegible] with different lengths of exposure [illegible]

Group X——X [illegible] Xs = [illegible]
O O [illegible] Xs = [illegible]

Fig 2

some disconcerting and unexplained discrepancies which appeared when the curves were compared with hearing loss curves from other studies

Specifically, the average hearing losses at the higher frequencies for both groups from the aircraft plant, (riveters and flight line mechanics) are less than hearing losses for *any* occupational group, even for office workers, measured at a State Fair Hearing Survey conducted at Milwaukee, Wisc, in 1954 This result suggests that a search should be made for possible sources of bias in both sets of data Some unspecified selective factors may have operated in the assign-

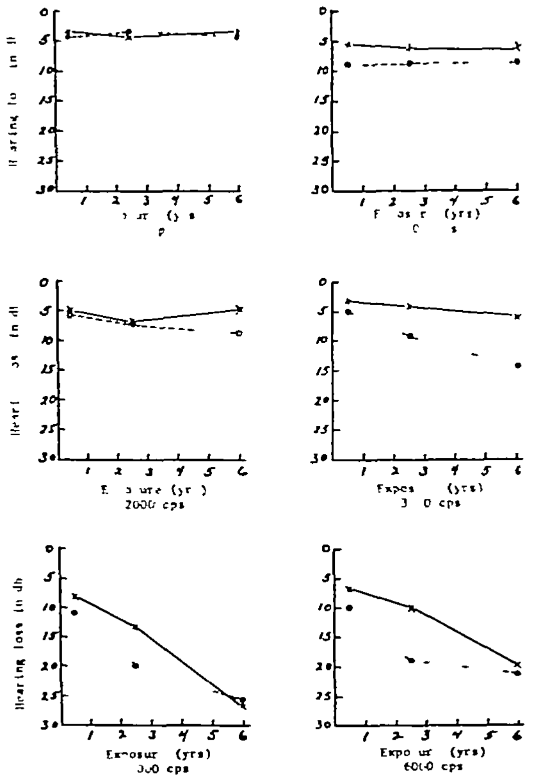


Median hearing losses for male factory workers with different lengths of noise exposure Right ear only

Fig 1

does hearing loss increase at tested frequencies above 3000 c p s

The data were also analyzed with respect to differences in hearing loss that might occur in different occupations in the aircraft company A comparison of the hearing losses of riveters and of jet flight line mechanics may be made from the curves presented in Fig 3 Note that there is a consistent difference between the median losses of the two groups, but that the flight line mechanics have the better hearing in all age groups The differences are probably statistically significant, but tests for statistical significance were not made because of



Median hearing loss for 1190 workers with riveting experience with different lengths of exposure Right ear only

Groups X——X 18 year age Ns = 60 161 2
O O 26 3 year ages Ns = 169 143 93

Fig 2

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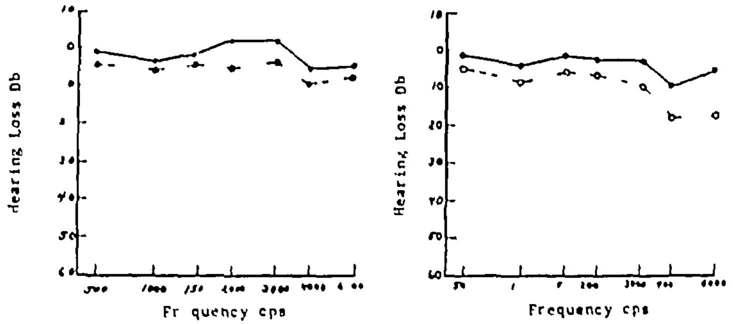
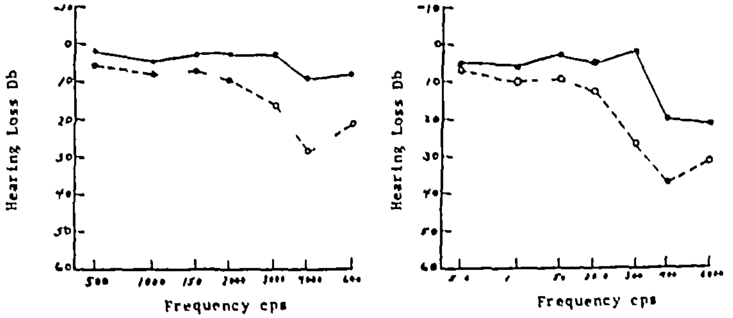


(18 25 Year Age Group)

(26 35 Year Age Group)



(36 45 Year Age Group)

(46 Year and Older Group)

Comparison of median hearing losses for men with riveting experience and with jet engine flight line exposure  Right ear only

Groups •—— Jet engine flight line exposure
o —• Riveting

Fig 3

ment of men to a particular work category in the aircraft plant, then too, the audiograms in this plant may have been influenced by certain medical referral policies

The records with the serial audiograms were checked carefully for obvious errors such as decreasing age, impossible changes in years of noise-exposure such as a history of five years in noise on one record and six months later a history of seven years in noise, etc  These data showed errors of this type in less than 1 per cent of the records

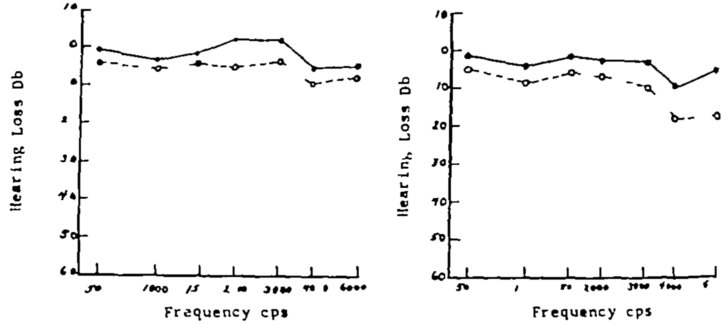
What then have we learned from this analysis? The data indicate that in general, high frequency hearing loss increases with increase in noise-exposure time up to six years, the time period for which data were available, that within the company jet flight line mechanics show less loss than riveters, and that these riveters and mechanics show less hearing loss than do comparable age groups in another study of men in what are considered to be *non-noisy* occupations Findings such as the latter are unexplained at present, and we are understandably reluctant to accept at face value, or to publish without explanation, the results of this and other similar studies

Our experience, as exemplified in the study above, has indicated that many of the differences between groups of data are not strictly related to differences in noise-exposures, or even to such relevant factors as age Before we can draw valid conclusions about the relation of hearing loss to noise-exposure, we must find ways to minimize the importance of, or to control statistically the factors that are not related to the noise-exposure The remainder of this paper will be devoted to a discussion of some of the difficulties encountered in gathering and analyzing data from field studies of noise-induced hearing loss and to a brief description of attempts that are being made to effect the necessary controls

## EXPERIMENTAL DIFFICULTIES

In the main, the difficulties encountered in our field research in industry are of two kinds those peculiar to studies of noise-induced hearing loss and those common to all experiments Three of the problems peculiar to studies of noise-induced hearing loss are

1 *Description of Noise-exposure* One of the most difficult problems associated with a study of noise-exposure is that of devising a method of describing and categorizing in a meaningful way the multitudinous types of noise-exposure encountered In order to describe noise-exposure adequately for correlation purposes, some numerical method of classification must be evolved This method of classification must provide a way of combining the measurement of quantity of sound



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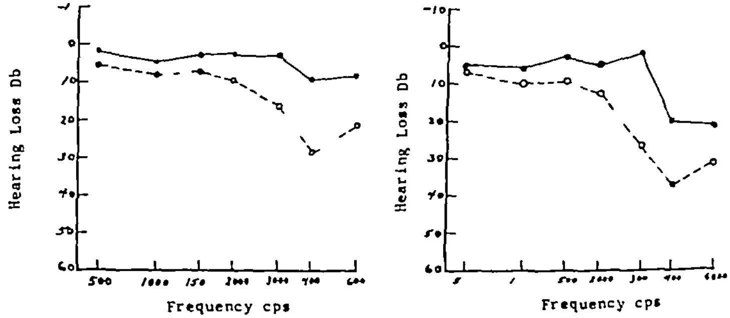

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What then have we learned from this analysis? The data noise-exposures from measurements of their physical parameters, the second goal, which I fear will not be realized for some years, will be to index the auditory effects of various noise-exposures on man

2 *Temporary Threshold Shift* A second difficulty peculiar to studies of hearing loss is caused by the temporary hearing loss that results from several hours exposure to noise Recovery from this loss is usually complete a few hours after cessation of exposure, with the major part of the recovery normally occurring in the first 30 to 60 minutes The existence of this temporary loss, or *temporary threshold shift,* has an important influence on the validity of field data Recent measurements made in our laboratory indicate that at 4000 c p s the temporary threshold shift resulting from two hours' exposure to white noise may be less than 5 db in one person and more than 35 to 40 db in another Fig 4 shows the mean threshold shift of a group of ten subjects whose hearing was measured at half-hour intervals, during and after a two-hour exposure to white noise of 100 db overall sound pressure level There appears to be no systematic variation in the size of the shift experienced by different individuals

We have also made field measurements of the temporary threshold shift caused by exposure to typical industrial noises These measurements were made throughout the workday on several hundred employees of an aircraft company The field findings confirmed the laboratory findings

If industrial hearing tests are made late in the workday after employees have experienced several hours of exposure to noise, the resulting audiograms will be contaminated by temporary threshold shifts Temporary threshold shift, as a function of the time of day the audiogram is made, can cause a considerable variation in an individual's audiograms, therefore, if some correction for temporary threshold shift is not applied to industrial audiograms the true threshold of hearing will be disguised by temporary threshold shifts, and much of the available field data will not be suitable for studies of permanent hearing loss energy with measurements of its time distribution. The result might be called a "noise-exposure-index." One approach to the total problem would be to index noise-exposure first with respect to its *physical dimensions,* and then as a further step, to index the effects of the noise-exposure on man. The problem of assessing noise-exposure is very complex, and large amounts of data must be gathered and analyzed before we can say what a practical and useful assessment of noise-exposure is.

Recent measurements indicate that sufficiently detailed information about the energy content of noise-exposure is not provided by RMS measurements. A report from Harold Crouch, of Eastman Kodak Co., shows that although the RMS values of overall levels of certain so-called "steady state" noises were in the region of 100 db., the instantaneous levels were as high as 120 db. for 10 per cent or 15 per cent of the time. In my opinion, evidence such as this must not be overlooked. We may find that peak factors in noise-exposure correlate better with resulting hearing loss than do some of the factors we have already considered, such as the frequency distribution of energy in the noise-exposure. In spite of the variability of the industrial processes and of the accompanying noise-exposures, large numbers of industrial audiograms show the same type of hearing loss: the loss begins in the region of 4000 c.p.s. and spreads in both directions as exposure time increases. It appears then, that energy content of noise, its peaks, its time distribution and its total duration, regardless of spectral distribution, are factors which bear close scrutiny.

Although we are cognizant of the fact that time plays a part in the production of hearing loss, we have not yet learned what time interval is most suitable for correlation purposes; should it be one work day, one work year, or some point between?

The Research Center of the Subcommittee on Noise in Industry has recently undertaken a program of gathering and analyzing detailed information about noise-exposures. The first goal of this program is to devise a method of indexing noise-exposures from measurements of their physical parameters, the second goal, which I fear will not be realized for some years, will be to index the auditory effects of various noise-exposures on man

2 *Temporary Threshold Shift* A second difficulty peculiar to studies of hearing loss is caused by the temporary hearing loss that results from several hours exposure to noise Recovery from this loss is usually complete a few hours after cessation of exposure, with the major part of the recovery normally occurring in the first 30 to 60 minutes The existence of this temporary loss, or *temporary threshold shift,* has an important influence on the validity of field data Recent measurements made in our laboratory indicate that at 4000 c p s the temporary threshold shift resulting from two hours' exposure to white noise may be less than 5 db in one person and more than 35 to 40 db in another Fig 4 shows the mean threshold shift of a group of ten subjects whose hearing was measured at half-hour intervals, during and after a two-hour exposure to white noise of 100 db overall sound pressure level There appears to be no systematic variation in the size of the shift experienced by different individuals

We have also made field measurements of the temporary threshold shift caused by exposure to typical industrial noises These measurements were made throughout the workday on several hundred employees of an aircraft company The field findings confirmed the laboratory findings

If industrial hearing tests are made late in the workday after employees have experienced several hours of exposure to noise, the resulting audiograms will be contaminated by temporary threshold shifts Temporary threshold shift, as a function of the time of day the audiogram is made, can cause a considerable variation in an individual's audiograms, therefore, if some correction for temporary threshold shift is not applied to industrial audiograms the true threshold of hearing will be disguised by temporary threshold shifts, and much of the available field data will not be suitable for studies of permanent hearing loss

In what ways can we control the effect of temporary threshold shift? Ideally, we might use only those audiograms that were made at least 16 hours after cessation of exposure to noise This obviously limits us to too few audiograms for good statistical analyses On the other hand, it is impossible for industry to make all audiograms at the beginning of the workday before employees have been exposed to noise Our most fruitful approach seems to be to devise some valid statistical method for controlling the effect of temporary threshold shift We hope to gain enough information from our laboratory studies and from analyses of large numbers of industrial records which include the time of day the audiogram was made to be able to devise such a method The laboratory measurements will tell us, for continuous exposure to noises which are similar to white noise, how much temporary threshold shift is to be expected on the average at different hours during the work day Incidentally, it should

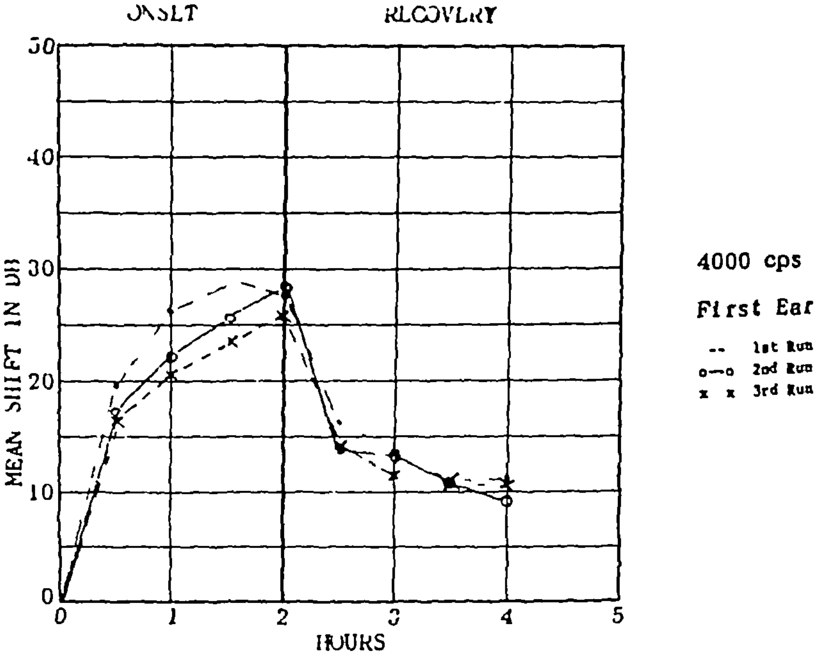

Fig 4

be made clear that recording the time of day the audiogram was made is not sufficient, a statement which describes the amount of noise-exposure prior to the time of giving the hearing test should also be included Further, there are promising indications from our studies of industrial records that if we have a measure of the noise-exposure we may be able to use late-in-the-day audiograms to predict the average "pre-exposure" threshold for a group of employees, or as I prefer to call it, the average *resting* threshold for the group

*3 Hearing loss that accompanies age* A third difficulty which besets the study of noise-induced hearing loss is the compounding of inner-ear hearing losses due to several causes Age, otological disease and noise-exposure may all produce inner-ear hearing loss There is no way of telling from the individual audiogram which of these causes produced a given loss Assuming that we can identify all cases of otological disease from medical histories and so can eliminate them from samples to be studied, we are still faced with the problem of separating noise-induced hearing loss from "age-induced" hearing loss

There is a semantic difficulty here as well as a procedural problem Let me explain The word most commonly used to denote loss of hearing with age in "presbycusis" Strictly speaking, "presbycusis" denotes only that there is a relation between hearing loss and age, it does not specify what the relation is The meaning of the word has become somewhat restricted, however, by usage and by analogy with the restricted meaning of other terms containing the prefix "presby-" In medical literature, the word "presbycusis" has been used commonly to denote hearing loss that accompanies age and that results only from physiological changes that occur with the passage of time Schuknecht* describes the cause of presbycusis as "degenerative changes beginning at the basal end of the cochlea and extending toward the apex, affecting almost equally and simultaneously the various structures within the cochlear duct, including the afferent and efferent nerve fibers The formation of this atrophic lesion resembles the age process known to affect other tissues as age increases"

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*Schuknecht, H. F Prebycusis The Laryngoscope 45 402-419 June 1955

Although the term "presbycusis" is not now so restricted, we feel that it should be reserved to denote specifically the hearing loss that is produced as a result of the aging process, and that is not directly related to environmental factors In addition to the term "presbycusis," then, we need words to describe inner-ear hearing losses caused by noise-exposures The large hearing losses of noise workers certainly cannot be considered as a true reflection of changes produced by age alone, in part, these losses are caused directly by the environment There is also some indication that a large proportion of the population, including persons not employed in noisy occupations, may sustain an average noise-induced hearing loss that is greater than presbycusis but is considerably less than the average noise-induced occupational loss This smaller noise-induced loss results presumably from exposure to social and domestic noises that are common in our society We are now making measurements to determine the magnitude of this loss

At this time we consider inner-ear hearing losses not caused by otological disease to be made up of one or more of these three losses

*1* The loss produced by physiological aging processes, or "presbycusis" Presbycusis has no direct causal relation to noise-exposure

*2* The loss produced by noise-exposures not greater than those found in ordinary environmental social situations For want of a better term this hearing loss might be called "sociocusis" Sociocusis is causally related to the noise-exposure encountered in non-occupational pursuits and/or in occupations where the noise levels do not ordinarily exceed those found in our social environments The noise-exposures in most offices, for example, are less than the exposures one encounters in many social and domestic activities such as riding in an automobile with the windows open, operating washing machines, vacuum cleaners, electric mixers and other noise producing home appliances These two losses, presbycusis and sociocusis, are not necessarily related to one's occupation Disease, diet, stress and social environmental noise undoubtedly produce a gradual loss of hearing which increases with advancing age This concept of "wear and tear" on the auditory system from non-occupational causes must be considered if we are to come to any sensible decision regarding noise-induced hearing loss

*3* The loss produced by industrial or military high level noise-exposures, or, if you will, "occupational hearing loss"

In order to draw conclusions regarding the auditory effects of specific noise-exposures we must provide a method for separating out the non-noise-exposure-related hearing loss Our present concept is that occupational hearing loss and the hearing loss accompanying age are additive losses The true nature of the interrelation of noise-exposure and other causes of hearing loss remains to be determined, but until it is, we shall continue to assume that inner-ear hearing losses, from whatever cause, are additive Under this assumption we determine the average occupational hearing loss as follows *1* measure the total hearing loss, *2* subtract from this measured hearing loss the amount of loss to be expected from non-occupational causes, the remainder is the occupational hearing loss How large is the expected non-occupational loss? The answer may be found by measuring the hearing of many persons who have no otological disease and who have not been exposed to high noise levels for extended periods of time The curves shown in Figs 5 and 6 are representative of the "non-occupational hearing loss that accompanies age" for males and females respectively These curves "summarize" the hearing measurements made on several hundred male office workers and female office workers, housewives, etc, with no history of disease or occupational noise-exposure

## FIELD EXPERIMENTS DIFFICULT TO CONTROL

Let us now consider some of the difficulties associated with the actual gathering of data in the field

*First,* from a practical standpoint the process of hearing measurement alone presents many almost insurmountable nerve fibers The formation of this atrophic lesion resembles the age process known to affect other tissues as age increases"

Although the term "presbycusis" is not now so restricted, we feel that it should be reserved to denote specifically the hearing loss that is produced as a result of the aging process, and that is not directly related to environmental factors In addition to the term "prebycusis," then, we need words to describe inner-ear hearing losses caused by noise-exposures The large hearing losses of noise workers certainly cannot be considered as a true reflection of changes produced by age alone, in part, these losses are caused directly by the environment There is also some indication that a large proportion of the population, including persons not employed in noisy occupations, may sustain an average noise-induced hearing loss that is greater than presbycusis but is considerably less than the average noise-induced occupational loss This smaller noise-induced loss results presumably from exposure to social and domestic noises that are common in our society We are now making measurements to determine the magnitude of this loss

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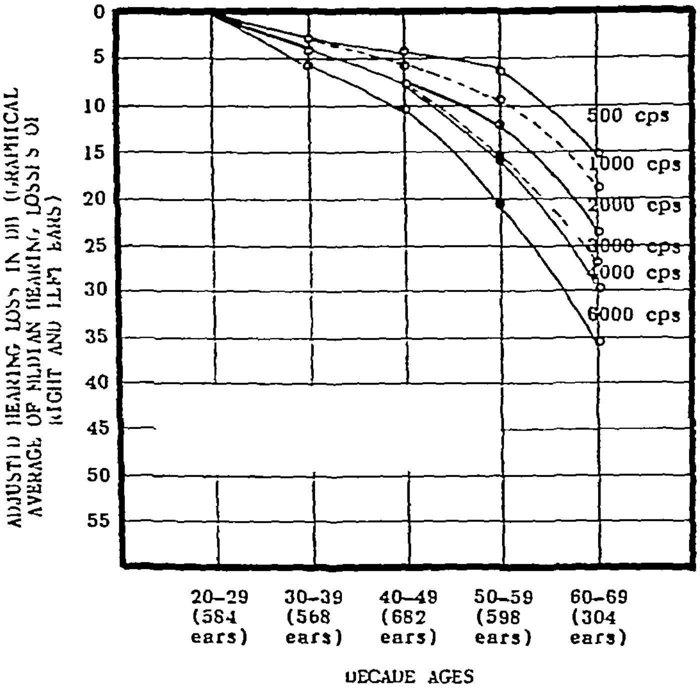


CURVES OF PRESBYCUSIS PLUS SOCIOCUSIS (NON-OCCUPATIONAL HEARING LOSS THAT ACCOMPANIES AGE) FEMALES WITH NO HISTORY OF OCCUPATIONAL NOISE-EXPOSURE 1954 WISCONSIN STATE FAIR HEARING SURVEY

Fig 6

*Second*, in spite of the availability of prefabricated test booths, the environmental conditions under which most industrial audiometry is done leave much to be desired We are now engaged in an educational campaign to make industrial and military physicians and technicians fully aware of the importance of proper test conditions The pertinent information is made available in the revised Guide, in journal articles, in special training courses offered for audiometric technicians, etc

*Third*, an examination of the methods of recording data reveals variations, inadequacies and errors which make it almost impossible to use much of the available material difficulties For research purposes we should have measurements of threshold responses to pure tone stimuli, but it is practically impossible to make such measurements for the employees in large industries A trend toward screening audiometry is becoming evident in the larger plants There is usually time for threshold tests during the pre-employment physical examinations, however, and we have consistently urged that threshold hearing tests be made a part of this examination We have also recommended that rapid follow-up tests of hearing or recheck tests be made for many employees with the single frequency screening method devised by Dr Howard House and myself The time saved by use of this screening technique should make it possible for most industries to give threshold tests to employees whose hearing has undergone a significant change These recommendations and many others have been made available to industry in our revised Guide for Conservation of Hearing in Noise, published in 1957

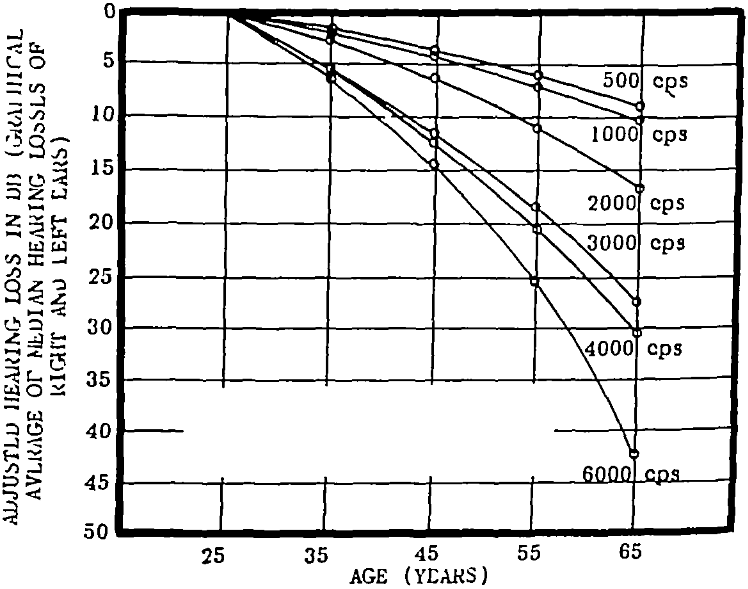


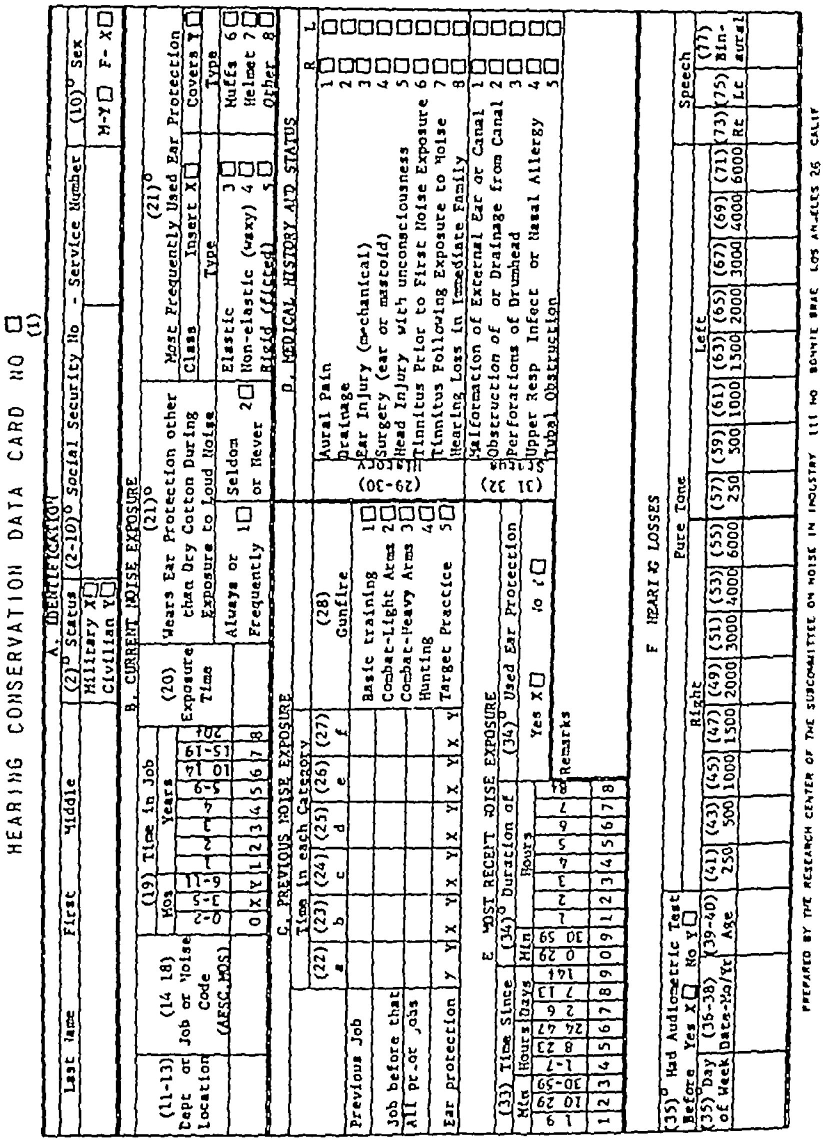
Fig 5 Curves of presbycusis and sociocusis (nonoccupational hearing loss that accompanies age) male office workers—1954 Wisconsin State Fair Hearing Survey (604 ears)

*Fourth,* one of the worst problems to contend with in the use of industrial data is the rapid turnover of personnel Very few noisy industries employ the same personnel over long enough periods of time for us to make fruitful studies of hearing loss The aircraft companies, for example, have almost a 100 per cent turnover per year in their noisy departments Consequently, it is unusual to be able to follow the same person with repeat tests for more than a few months at a time For this reason, we must obtain very large amounts of data if we are to draw valid conclusions about industrial hearing loss in general

*Fifth,* audiometric data is subject to the usual errors of sampling and measurement Such errors may make measured values consistently larger than or smaller than the "true" value Variable errors may cause measured values to fluctuate from one occasion to another and thereby "hide" changes or relationships in a maze of variable unstable numbers Company policy for assigning men to various jobs may give rise to sampling bias by producing an occupational group within the company that is not typical of the occupation in industry as a whole Errors may result from failure to control relevant factors while measurements are being made Audiometric measurements, for example, are known to be influenced by such effects as practice and fatigue Experimenters must be careful to equate comparison groups in such matters as age, sex, etc The calibration of the equipment must not be changed between the time of testing one comparison group and another

## CONCLUSIONS

In spite of the many very real difficulties that are encountered in field studies of industrial hearing loss we feel that industrial and military audiometric data can be used to good advantage if they are properly recorded and if the necessary supplementary information is included in each record For research purposes, industrial records should contain *at least,* *1* the age, in years, of the person tested, *2* a standardized specification of the noise environment, *3* an accurate record of the man's exposure history, *4* a statement of the reason



HEARING CONSERVATION DATA CARD NO ☐ (1)

A. IDENTIFICATION

Last Name | First | Middle | (2)° Status: Military X☐ Civilian Y☐ | (2-10)° Social Security No - Service Number | (10)° Sex: M-Y☐ F- X☐

B. CURRENT NOISE EXPOSURE

(11-13) Dept or Location | (14 18) Job or Noise Code (AFSC, MOS) | (19) Time in Job: Mos 0-2, 3-5, 6-11 (0, X, Y); Years 1, 2, 3, 4, 5-9, 10-14, 15-19, 20+ (1, 2, 3, 4, 5, 6, 7, 8) | (20) Exposure Time

(21)° Wears Ear Protection other than Dry Cotton During Exposure to Loud Noise: Always or Frequently 1☐ Seldom or Never 2☐

(21)° Most Frequently Used Ear Protection: Class Insert X☐ Covers Y☐; Type: Elastic 3☐ Non-elastic (waxy) 4☐ Rigid (fitted) 5☐; Type: Muffs 6☐ Helmet 7☐ Other 8☐

C. PREVIOUS NOISE EXPOSURE

Time in each Category: (22) a, (23) b, (24) c, (25) d, (26) e, (27) f

Previous Job

Job before that

All prior jobs

Ear protection Y Y X Y X Y X Y X Y X Y

(28) Gunfire: Basic training 1☐ Combat-Light Arms 2☐ Combat-Heavy Arms 3☐ Hunting 4☐ Target Practice 5☐

D. MEDICAL HISTORY AND STATUS

History (29-30) — R L
- Aural Pain 1☐ ☐
- Drainage 2☐ ☐
- Ear Injury (mechanical) 3☐ ☐
- Surgery (ear or mastoid) 4☐ ☐
- Head Injury with unconsciousness 5☐ ☐
- Tinnitus Prior to First Noise Exposure 6☐ ☐
- Tinnitus Following Exposure to Noise 7☐ ☐
- Hearing Loss in Immediate Family 8☐ ☐

Status (31 32)
- Malformation of External Ear or Canal 1☐ ☐
- Obstruction of or Drainage from Canal 2☐ ☐
- Perforations of Drumhead 3☐ ☐
- Upper Resp Infect or Nasal Allergy 4☐ ☐
- Tubal Obstruction 5☐ ☐

E. MOST RECENT NOISE EXPOSURE

(33) Time Since: Min 1-9, 10-29, 30-59 (1, 2, 3); Hours 1-7, 8-23 (4, 5); Days 24-47, 2-6, 7-13, 14+ (6, 7, 8, 9)

(34)° Duration of: Min 0-29, 30-59 (0, 9); Hours 1, 2, 3, 4, 5, 6, 7, 8+ (1, 2, 3, 4, 5, 6, 7, 8)

(34)° Used Ear Protection: Yes X☐ No Y☐

Remarks

F. HEARING LOSSES

(35)° Had Audiometric Test Before: Yes X☐ No Y☐

(35)° Day of Week | (36-38) Date-Mo/Yr | (39-40) Age

Pure Tone — Right: (41) 250, (43) 500, (45) 1000, (47) 1500, (49) 2000, (51) 3000, (53) 4000, (55) 6000; Left: (57) 250, (59) 500, (61) 1000, (63) 1500, (65) 2000, (67) 3000, (69) 4000, (71) 6000

Speech: (73) Rt, (75) Lt, (77) Bin-aural

PREPARED BY THE RESEARCH CENTER OF THE SUBCOMMITTEE ON NOISE IN INDUSTRY 111 NO BONNIE BRAE LOS ANGELES 26 CALIF

Fig 7

Recognizing the importance of accurate records, we devised a standard form for recording hearing conservation data. This form, called a "Hearing Conservation Data Card" is shown in Fig 7. The Data Card is unquestionably a step in the right direction, but undoubtedly it will be years before it will be accepted by industry in general.

and limitations, future industrial data can be used to good advantage if certain remediable faults are corrected

# A LABORATORY METHOD FOR THE STUDY OF ACOUSTIC TRAUMA *

DONALD H ELDREDGE,
and
WALTER P COVELL,

Central Institute for the Deaf and Washington University,

St Louis, Mo

To begin I should like to stress two points first, the work to be discussed here is part of a continuing project to learn more about acoustic injury of the ear Many others working at the Central Institute for the Deaf, especially Drs Davis, Riesco-MacClure, Fernández, Tasaki, Legouix, Goldstein and Benson, have made major contributions to these techniques in the past Dr Davis continues as our most helpful advisor, and, when he has time left over from his many other duties and researches, is still an active collaborator

Second, we are really studying acoustic trauma in the laboratory, and this is quite different from the subject matter of the other presentations of this morning Ideally, in planning this program Drs Silverman and Hirsh would like to have had someone describe the pathologic physiology of human ears which had been exposed to the noise of, say a drop forge for 5, 10, 20 and 30 years This is not possible, and so we are to discuss acoustic injuries to the guinea pig ear We would like to know about real deficits in hearing function, but we must look at cochlear potentials and cochlear anatomy in the guinea pig We would like to know about exposures that continue for years, instead, our experimental exposures last minutes to hours Although some results from our experiments will be presented, the title, "A Laboratory Method for

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for making the audiogram, and *5* the date and time within the work cycle when the measurement was made

## SUMMARY

Finally, let me summarize the main points of the paper *1* Design in industrial field research is largely restricted to appropriate tailoring of existing data production methods It is unlike laboratory research where experiments can be designed to yield the type of data needed, and since manipulative controls are not feasible, statistical controls must be provided during analysis of the data—a situation which generally requires the collection of very large amounts of data *2* Many restrictions are imposed on the use of audiometric data obtained through usual industrial channels, because most industrial groups are not homogeneous as to noise-exposure history, job continuity, use of ear protection, and time of hearing test during a day Further, because companies differ in their method of record keeping, the data are likely to vary in respects that may limit the usefulness of the information in studies which combine company samples Although such restrictions do not make the data useless they do point out the need for careful scrutiny and skillful analysis if valid conclusions are to be drawn *3* There are a large number of specific factors which can reduce the validity of data collected in industrial situations Some of these factors can be eliminated For example, poor testing environments poorly trained audiometric technicians, obvious errors in data recording, and nonstandard or inadequate methods of data recording On the other hand, there are many conditions which cannot be altered For example, it is improbable that industry in general will be able to make all audiograms after a period of absence from noise-exposure *4* Data will be more useful if the forms used to record the data are standardized In a standard form particular attention should be paid to details of noise-exposure, to time of hearing tests, and to the reason for the hearing tests *5* Explanations for some of the discrepancies disclosed in industrial data are (a) biases operating in the selection of the sample and (b) nonrepresentativeness of the audiograms *6* In spite of restrictions the values for "threshold" shift corresponding to these injuries is slightly less, the general trend is the same

The preparation of good temporal bone specimens for microscopic study is a slow tedious process, and the "feedback" of information from one experiment to the next is very slow if we rely solely on this method, however, one knows the "threshold" shift for the CM immediately, and using the information from this slide, can quickly estimate the anatomical degree of an acoustic injury In addition, other electrophysiological potentials can be measured When these are compared to each other and to the anatomical injuries later observed, there is a good possibility that our understanding of the pathologic physiology of acoustic trauma will be improved These ideas were basic to our plans for the experiments I will describe

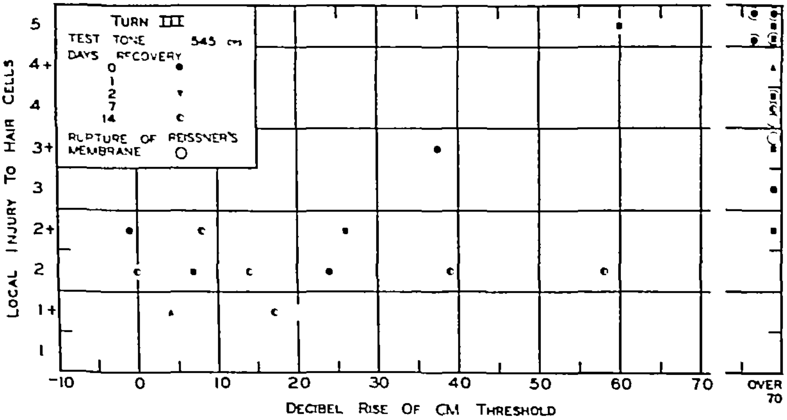


Fig 2 Local injury to the hair cells in the third turn plotted against decibels rise of CM threshold for 500 c.p s in the third turn The symbols correspond to the different durations of the recovery period.

Now let us ask a question about acoustic trauma What reciprocal changes in the intensity and duration of an acoustic stimulus will produce a constant injury to the organ of Corti? For years we have been aware that brief, but intense, stimuli (for example, an explosion) can leave a permanent hearing loss Other stimuli which are apparently harmless for short the Study of Acoustic Trauma," was chosen to emphasize that we are not talking about Hearing Loss and Noise Exposure in the main sense of this session

Some time ago Hallowell Davis[1] and the numerous collaborators mentioned earlier noted a relation between the "threshold" shift for the cochlear microphonic as recorded by differential electrodes placed in scala vestibuli and scala tympani, and the anatomical injury observed between these electrodes after acoustic trauma This relation is shown in Fig 1 The ordinant is an anatomical injury rating scale of nine points Injury ratings of 3, 3+, 4, and 4+ were considered to represent probably permanent injury to the hair cells of the organ of Corti, and were associated with "threshold" shifts of the cochlear microphonic potential of about 40-60 decibels Fig 2, taken from one of our more recent papers,[2] shows the same relation measured after the ears had been allowed to recover from the acoustic trauma for periods up to 14 days Although

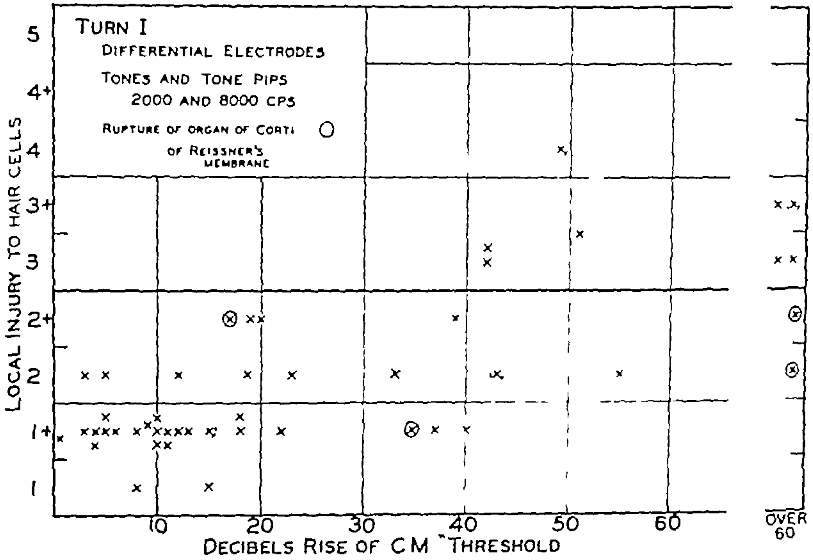


Fig 1 The elevation of the "threshold" of the cochlear microphonic as measured in Turn I by differential electrodes The ordinant is an anatomical injury rating scale of nine points The heavy horizontal line divides the probably permanent injuries to hair cells (above) from the probably reversible injuries (below) The crosses represent differential electrodes

ant, and the duration plotted logarithmically in minutes on the abscissa The number of ears in each group varied from one to ten Five to ten ears were used for exposures which gave 40 to 60 db "threshold" shifts, whereas only one, two or three were used to explore the exposures above and below this range Open circles designate average shifts of less

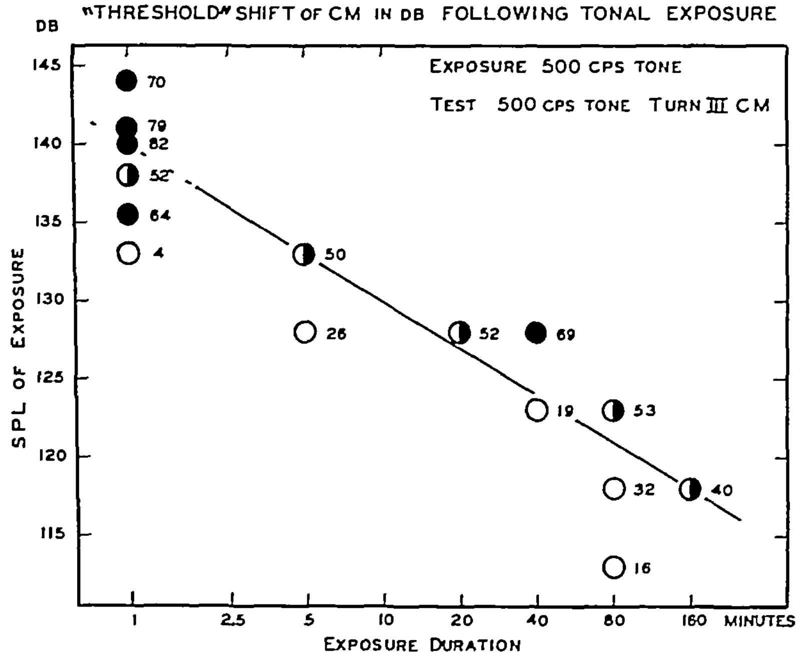


Fig 3 Sound pressure levels and durations of exposures to 500 c.p s tone Numbers indicate average threshold shift for CM from Turn III in response to 500 c.p s test tone Open circles indicate exposures which produced less than 40 db shift half-filled circles indicate 40 to 60 db shift and solid circles indicate more than 60 db shift Line described in text.

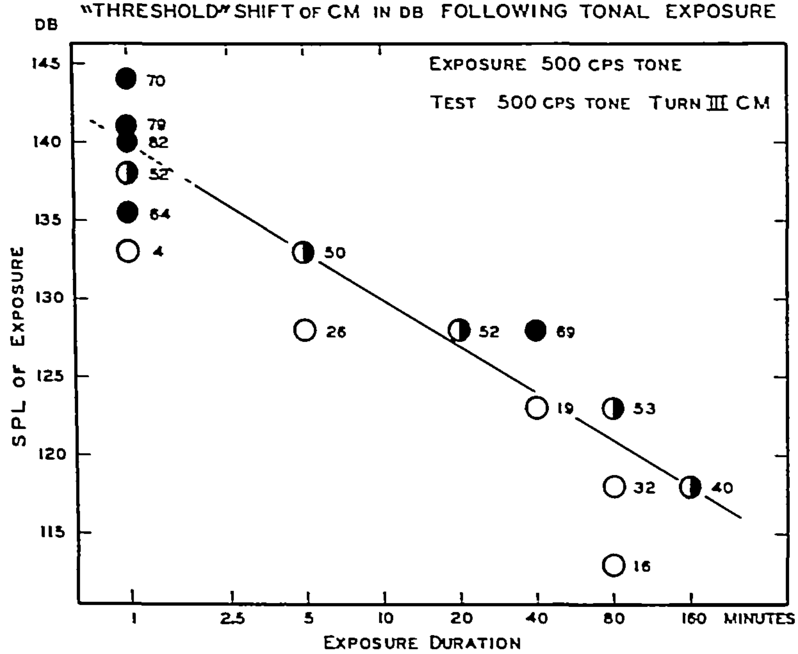
than 40 db, and filled circles represent average shifts of more than 60 db The half-filled circles designate the exposures which produced our criterion shift of 40 to 60 db

For a moment let us turn to the problem of chronic noise-induced hearing loss In trying to arrive at some reasonable way to relate the contributions of sound pressure level and duration of exposures to the hazard of noise exposure, an exposures can produce permanent hearing losses if the exposure is made sufficiently long There is a tremendous continuum between these durations, measured in milliseconds on the one hand and years on the other The first experiment to be described deals with durations of stimuli only between one and 160 minutes We consider these durations to fall in the category of acute acoustic trauma, not chronic noise-induced hearing loss

For the traumatic stimulus we used a 500 c p s tone generated by an enclosed acoustic system sealed to the ear canal of the guinea pig This acoustic system was very stable, and carefully calibrated so that we could specify the sound pressure level of the stimuli at the tympanic membrane within ±2 db Remembering yesterday's presentations, a 500 c p s tone will stimulate all the turns of the cochlea nearly to the apex The greatest amplitude of motion in the basilar membrane will appear in the third turn We would expect the more severe injuries here also, with lesser or possibly no injuries elsewhere along the basilar membrane

Pairs of differential electrodes recording from the first and the third turns were used to measure the cochlear microphonics generated at these two locations The "threshold" shift for the cochlear microphonic produced by a 500 c p s test tone, and measured from the third turn, should indicate the more severe injury The same measure, "threshold" shift for the CM produced by test tones (we used 500, 2000 and 8000 c p s ) recorded from the first turn should indicate the degree of anatomical injury in the first turn To avoid the effects of transitory fatigue, the measurements were made one hour after the end of the traumatic stimulus

Taking some clues about critical exposures from previous experiments, we set about exposing guinea pig ears to the 500 c p s tone, planning the experiments as we went along The idea was to use exposures which would "bracket" our criterion injury as indicated by "threshold" shifts, measured in the third turn for a 500 c p s test tone In Fig 3 are shown the exposures used and the average "threshold" shifts for the various exposure conditions Each point represents one group of exposures to the sound pressure level shown on the ordinant, and the duration plotted logarithmically in minutes on the abscissa The number of ears in each group varied from one to ten Five to ten ears were used for exposures which gave 40 to 60 db "threshold" shifts, whereas only one, two or three were used to explore the exposures above and below this range Open circles designate average shifts of less than 40 db, and filled circles represent average shifts of more than 60 db The half-filled circles designate the exposures which produced our criterion shift of 40 to 60 db



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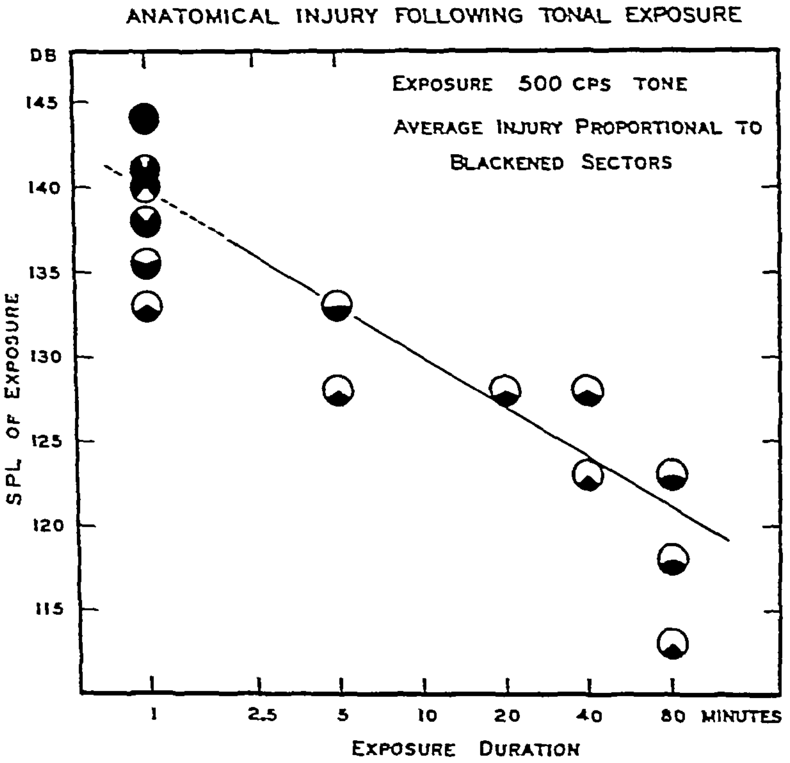
ANATOMICAL INJURY FOLLOWING TONAL EXPOSURE

Fig 4 Sound pressure levels and duration of exposures to 500 c p s tone as in Fig 3. Injury of hair cells in Turn III proportional to amount of blackening of circles

that the sound pressure level decreased only one decibel each time the duration of exposure is doubled, however, we must do the experiments which would "bracket" this new parameter before the parameter can be drawn with any degree of assurance In particular, we must learn the sound pressure thresholds for severe injuries at the longer durations of exposure.

The best we can do so far is to alter our concept of the relation between anatomical injury and "threshold" shift for the cochlear microphonic responses Both can be produced by acoustic trauma, but each relates differently to the exposure dimensions of pressure and duration There is the further condition that definite injury to the organ of Corti equal-energy hypothesis has been proposed by Eldred, Gannon and von Gierke[3] Although there are no direct data to support this hypothesis, the relations so described do not conflict with common experience, and do appear to be more reasonable than other arbitrary assumptions one could make The hypothesis assumes that noise exposures may be equated with respect to hazard when the total acoustic energies of the exposures are equal A set of such equal exposures can be described on a double logarithmic plot of sound pressure and duration by a straight line with a slope such that it goes down 3 db in sound pressure level each time the duration of exposure is doubled

A line which drops 3 db for each doubling of duration has been drawn through the exposure point described by 133 db for five minutes and which gave an average "threshold" shift of 50 db This line rather well describes the parameter of our 40 to 60 db "threshold" shift criterion It does not do so well for the one-minute exposures, and we have reason to suspect that the function described by this parameter is reaching a limit at these sound pressure levels There must also be a similar lower limit, but this has not been sought systematically Parenthetically, I should note that this line should not be confused with other equal-energy parameters which have been proposed as safe for human ears

Before becoming too entranced with the possibilities for speculation on the good agreement between these data and the equal energy hypothesis, we ought to review the pathology produced in these ears The anatomical injuries to the hair cells of the organ of Corti in the third turn were rated on the same nine-point scale which was the abscissa of the first slides In Fig 4 the average injury ratings are depicted by the blackened sectors of the circles These circles are, of course, located in the same exposure position as on Fig 3, and the same equal-energy line has also been carried forward to provide a common reference It is clear that the degree of injury was primarily proportional to sound pressure level, although longer durations of exposure did slightly increase the injury ratings The injury ratings of some of the peripheral points invite a new line, which might have a slope such equal-energy hypothesis has been proposed by Eldred, Gannon and von Gierke[3] Although there are no direct data to support this hypothesis, the relations so described do not conflict with common experience, and do appear to be more reasonable than other arbitrary assumptions one could make The hypothesis assumes that noise exposures may be equated with respect to hazard when the total acoustic energies of the exposures are equal A set of such equal exposures can be described on a double logarithmic plot of sound pressure and duration by a straight line with a slope such that it goes down 3 db in sound pressure level each time the duration of exposure is doubled

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It is quite possible that our original injury rating scale is appropriate only to injuries produced by stimuli which produce motions that exceed certain elastic limits We may need to develop a new scale for rating the injuries produced by the lower sound pressure and longer duration exposures

Another question we have asked is "how do pure tones compare with noises in their ability to injure the organ of Corti?" The critical band hypothesis, which has been found extremely useful in psychophysical experiments, suggests one possible relation Given a flat spectrum noise which just masks a pure tone, only a narrow band of frequencies around the pure tone actively contributes to the masking This critical band of frequencies has the same acoustic energy as the pure tone The overall pattern of stimulation on the basilar membrane for the tone and for the critical band can be inferred to be the same or very nearly so, and to be equally broad If injury to the organ of Corti depends upon the energy actually delivered to a particular region of the basilar membrane we would expect a pure tone and its critical band to be equally injurious

A 300-600 c p s band of noise contains more frequencies than the critical band for 500 c p s, and presumably distributes energy to a larger portion of the basilar membrane than does a 500 c p s tone If the total energy delivered to the basilar membrane is the same for the 300-600 c p s band of noise and for the 500 c p s tone, the area of the basilar membrane giving the greatest response to 500 c p s tones will have a higher energy density when the stimulus is the tone, than it will have when the stimulus is the band of noise Data supporting the critical band hypothesis in man tell us that the energy concentration in this area should be about 7 db more for the pure tone If the injury at this location on the basilar membrane depends upon the energy density, it should be necessary for the overall rms level of the 300-600 nearly always produces a deficit in the cochlear microphonics as we measure them, whereas a deficit in the cochlear microphonic response is not always accompanied by the definite injuries we are accustomed to recognize as such

In Fig 5 is shown one injury that is more difficult to interpret in terms of probable function than others we have seen more often in the past The hair cells of the organ of Corti do not appear badly injured, but the Deiters cells supporting them have been injured to the extent that portions of these cells are torn off and deposited in the tunnel of Corti From other studies[2] we infer that these hair cells should regain a normal appearance, but we do not know whether they will be properly attached to the basilar membrane by the Deiters cells so that they can function normally Similarly we are not sure of the functional significance of loss of mesothelial cells Absence of mesothelial cells does not preclude normal

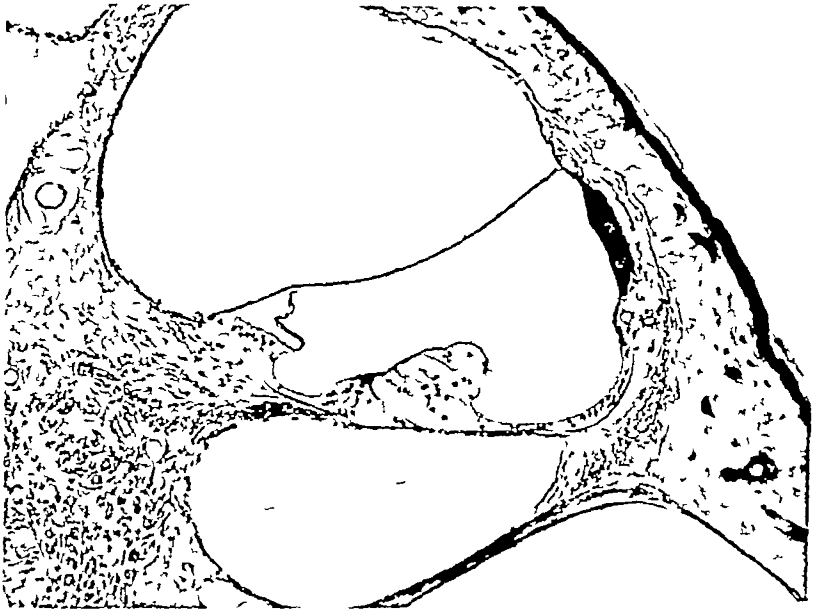

Fig 5 Photomicrograph of a section through the third turn of a guinea pig cochlea showing reasonably intact organ of Corti except for Deiters cells Some are detached from the basilar membrane and globules of their protoplasm appear in the tunnel of Corti—115X.

exposure condition which produced a 40 to 60 db "threshold" shift for the CM from the third turn is six db below the corresponding sound pressure level for the pure tone For this exposure condition we must clearly accept the hypothesis that the peak displacements are primarily responsible for the "threshold" shifts observed At the lower levels and longer

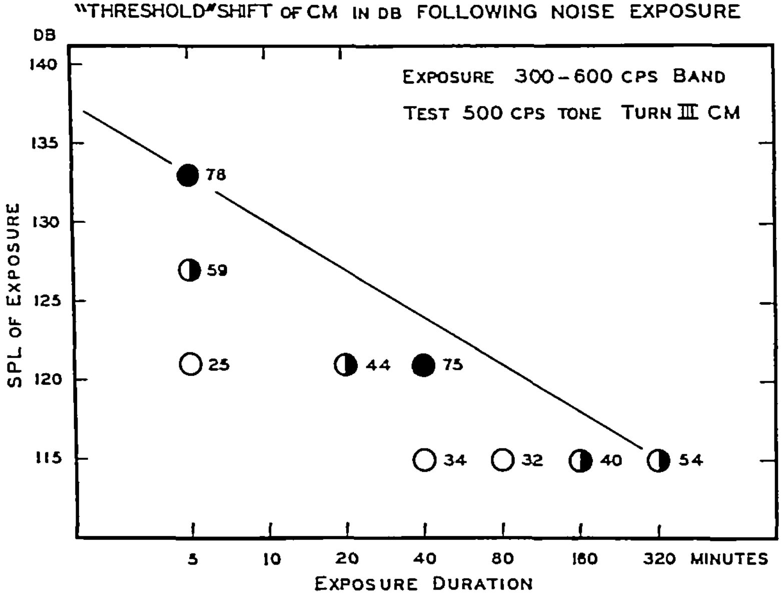

Fig 6 Sound pressure levels and duration of exposures to 300-600 c.p s band of noise Numbers indicate average threshold shift for CM from Turn III in response to 500 c p s test tone Open circles indicate exposures which produced less than 40 db shift and solid circles indicate more than 60 db shift. Line is from Fig 3 for comparison

durations there is a tendency for the exposure conditions yielding the criterion "threshold" shifts to approach this parameter for the pure tone exposures The data are not sufficient to determine really precise locations or limits for either set of experiments Rather than drawing a second line for the band of noise experiments, we prefer to state that it is different from that for the pure tone and starts at lower sound pressure levels Already we are stretching the time limits for acute experiments of this kind Both the tone and the band of noise parameters could be approaching the same c p s band of noise to be seven db more than the rms level of the pure tone The noise should then injure a *longer* segment of the basilar membrane, but the most severe local injuries should be the same We do not know the width of a critical band for the guinea pig It should not, however, be different in kind if the critical band hypothesis depends on the space-time pattern of the waves in the basilar membrane, as is assumed for the purposes of this experiment

It is also possible that peak displacements of the basilar membrane, rather than average energy level, are primarily responsible for the injuries we observe This hypothesis depends on the concept of exceeding some elastic limit in the tissues The peak displacements produced by a pure tone are, of course, uniform with respect to time A band of noise of the same overall level will produce displacements of random amplitude both greater and less than that of the pure tone Considerably greater displacements will occur occasionally and could produce more severe injuries We have not tried to quantify the differences, because we do not know the elastic limits of these tissues, however, if injury does depend on peak displacement, the overall sound pressure level of a band of noise required to produce a given injury will be less than that of the pure tone

It is, of course, also possible that the injury may in some way depend primarily on the total energy delivered to the cochlea In this case the injuries should be the same when the overall rms levels of the band of noise and the pure tone are the same

Again using the 40 to 60 db "threshold" shift of the CM, recorded from the third turn, to a 500 c p s test tone as our criterion, we have exposed guinea pig ears to a carefully calibrated 300-600 c p s band of noise The results are shown in Fig 6 The coordinants and the symbols are the same as for Fig 3, showing the "threshold" shifts produced by the pure tones The line which corresponded to the 40 to 60 db "threshold" shift parameter for the pure tone exposures also appears for comparison

For the five-minute exposure the sound pressure level of an exposure condition which produced a 40 to 60 db "threshold" shift for the CM from the third turn is six db below the corresponding sound pressure level for the pure tone For this exposure condition we must clearly accept the hypothesis that the peak displacements are primarily responsible for the "threshold" shifts observed At the lower levels and longer

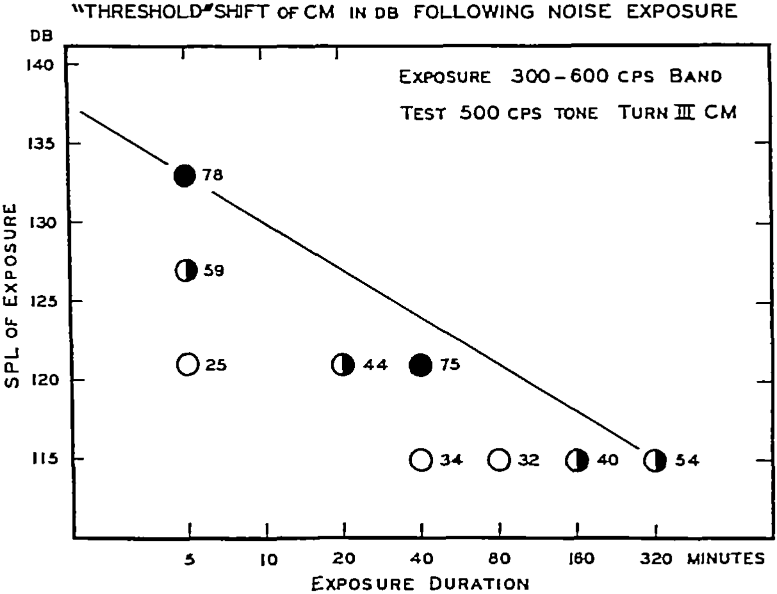

Fig 6 Sound pressure levels and duration of exposures to 300-600 c.p s band of noise. Numbers indicate average threshold shift for CM from Turn III in response to 500 c p s test tone Open circles indicate exposures which produced less than 40 db shift and solid circles indicate more than 60 db shift. Line is from Fig 3 for comparison

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The temporal bone specimens injured by the band of nois are quite comparable to those injured by the pure tones with respect to the amount of injury to hair cells. As for the exposures to the 500 c.p.s. tone, the shorter, higher-level exposures injured the hair cells more severely than the longer, lower-level exposures. Both stimuli produced maximum degree of injury in the third turn of the cochlea. The areas of injury differed in that the injuries produced by the tone often spread to the upper part of the second turn, while the injuries produced by the band of noise spread toward the fourth turn and often to the apex. It is our impression that there may be other differences. The displacements of cells within the organ of Corti appear relatively greater and more obvious following the noise exposures, and gross rupture of the organ of Corti and of the reticular lamina are less frequent. These displacements are often accompanied by deformation of the tunnel of Corti and by a more frequent swelling of Deiters cells, which then appear to encroach upon and deform the hair cells. The internal phalangeal cell may be tremendously enlarged and the internal hair cell actually displaced. Stretching and rupture of Reissner's membrane occurs more frequently following the longer exposures to the band of noise. For the longest exposures, injury to Reissner's membrane was apparent even when injuries to the hair cells were minor and loss of CM responses only 20 to 30 db. The exposure to the tone (500 c.p.s.), on the other hand, usually appeared to injure more directly the hair cells and the mesothelial cells.

The pathological differences noted are only trends, and may not prove to be significant. Thus we believe the inferences we have drawn from the data on "threshold" shift of the CM responses are correct with respect to the relative hazards of pure tones and bands of noise for the brief intense exposures we have used.

In summary, the "threshold" shift for the cochlear microphonic produced by acute acoustic trauma by a 500 c p s tone obeys the equal-energy hypothesis when the duration of exposure is between five and 160 minutes A 300-600 c p s band of noise at a lower overall sound pressure level than the 500 c p s tone produces the same threshold shift of the cochlear microphonic as the tone From this we conclude that the shifts are related to peak pressures of the stimuli rather than to the energy of the stimuli The same pathology is not observed for all exposure conditions which produce the same threshold shifts of the cochlear microphonic This relation of the observed pathology is consistent with the finding that peak pressures play such an important role in acute acoustic trauma

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# NOISE-INDUCED HEARING LOSS DIAGNOSIS, PRESBYCUSIS, SUSCEPTIBILITY*

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The diagnosis of noise-induced hearing loss is not a simple problem It would be convenient, indeed, if noise produced a hearing loss, the audiogram of which would differ materially from the audiograms of every other known cause of hearing loss Since this is not the case other factors in addition to an audiogram must be taken into consideration

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*Due to Dr Hoople s illness this paper was read by Dr Ben H. Senturia of St. Louis.

In the differential diagnosis of hearing losses, it is probable that the history given by the patient is one of the most important factors to be appraised Obviously, if there has been no exposure at all to noise, no matter what the audiometric curve may be, a demonstrated loss cannot be due to noise, however, if there is sufficient exposure to noise *and* hearing loss of the type usually found in patients who have been subjected to noise, then the demonstrated loss is probably due to this cause How comforting it would be if the last part of the preceding sentence could read "the demonstrated loss is surely due to noise" It is rare, medically, that one can be as positive as this This is because, with man and his diseases, the blacks and the whites do not stand apart, they are mixed Thus, one is confronted with the problem of ascertaining the amount of black and the amount of white in the presenting grey This problem comes to the fore when patients who have been exposed to noise, and who have a demonstrable loss, are brought before juries or compensation referees, and doctors from one side testify there is little hearing loss due to noise, and medical testimony from the other side expresses the opinion that most of the loss is due to noise Both sides admit they are talking in terms of grey, but they cannot agree on the percentages of the black and white which make up the grey, thus, it is that judgment must come into this picture when all of the facts of a given case have been brought to light

With this in mind, there are several aspects in the history of such patients which can lend weight to one decision or the other

*1* The character of the onset of any hearing loss This symposium is concerned with industrial noise-induced hearing loss Sudden explosive noises are not included These sudden noises, if they are sufficiently loud, often produce a sudden hearing loss With industrial noise, the opposite of sudden explosive noise, it is conceivable though *highly* improbable that an exceptional susceptibility might account for a permanent sudden hearing loss This would be most unusual I have never seen such a case and have never heard of one, and inquiry among my colleagues yields a like experience, hence, there must be a history of gradual loss Usually the discovery of such a loss is made by the family or friends of the patient The loss is so gradual (when at last it begins to be a slight handicap) that the patient does not realize its presence

*2* Associated vertigo Sudden loss may have accompanying vertigo, but there is none with chronic noise-induced loss

*3* Accompanying tinnitus If this is present it is more than likely that one can elicit a history of an increase of its intensity late in the day of exposure, or in the following early evening hours It is also likely that a worker will state that his hearing seems to be poorer during these same time periods

*4* There is always some hearing loss in both ears, although one ear may have sustained greater loss than the other Careful inquiry into the exact nature of the individual's work pattern and his exposure to noise may reveal a cause for greater loss in one ear than the other In the great majority, however, the loss is essentially the same in both ears

*5* Further inquiry as to the patient's work conditions may suggest reasons why a loss is present Much noise in small enclosures or rooms with reverberating walls will cause more loss than similar noise in open spaces Work with pneumatic hammers, pneumatic drills, drop forges, riveting guns and chipping tools are notable for their contributions to hearing loss If further evidence of work conditions are available such as the overall intensity of the noise, its spectral characteristics, and the length of time an individual has been exposed to these noise conditions, judgment can be more correctly given as to the cause of a worker's hearing loss The time factor is most important Without considerable time spent in noise there will be no permanent loss In truth, there is no such thing as a hazardous noise in industry There is only hazardous noise *exposure*

*6* It should be obvious that inquiry should be made for other possible causes of hearing loss in a given patient This inquiry should be directed, not only to the ears but also to any diseases or accidents which might be contributing factors to a hearing loss This might prove to be time consuming, but the history should go even further to include the hearing experience of all known relatives

From these points it can be readily seen that the history can contribute much toward a correct decision as to how much black and how much white there may be in a given case, and certainly shows that a careful history should never be omitted in assaying a suspected noise-induced hearing loss

The second tool in the hand of the diagnostician, and one which is invaluable in arriving at a correct decision, is the examination of the patient as well as the assessment of his hearing Here, also, there are points of distinct value

*1* For this discussion we will pass quickly over the general examination of the patient, both physical and laboratory, but this may elicit a reason or reasons for a hearing loss

*2* Theoretically, the examination of the ears, nose and throat should be normal in an individual with noise-induced hearing loss for exposure to chronic noise causes no injury to these parts, *i e*, there should be a normal drum head, but this is almost tantamount to saying that noise cannot cause hearing loss in an ear which has been the victim of previous disease While a well marked conductive loss can give some protection, industrial noise can and does cause changes in the cochlea of such ears In this area are some of the most difficult decisions an otologist has to make, *i e*, how much of the loss of hearing that is present is due to noise and how much is due to the concomitant conductive lesion

*3* More substantial aid is given the examiner by hearing tests Significant findings include

*a* Bone conduction readings which parallel the air curves Should a bone-air gap be present some additional cause for the loss other than noise must be in the picture

*b* The air curve will show a loss which is greater at 4,000 c p s than any other frequency in almost every instance This is always true when assaying an early loss It is probably so in approximately 98 per cent of all cases, even when long exposure is known to be in the picture (see Fig 1)

*c* The frequencies below 500 are rarely affected If hearing at these frequencies is depressed, search should be made for other causes

| | 100 | 250 | 500 | 1000 | 2000 | 4000 | 6000 | 8000 | 11000 |
|---|---|---|---|---|---|---|---|---|---|
| A S | 0 | -5 | -5 | -5 | -5 | 40 | 30 | 20 | |
| Air— | | | | | | | | | |
| A.D | 0 | 0 | 0 | 0 | 0 | 40 | 35 | 25 | |

Fig 1

RIVETER

| | 100 | 250 | 500 | 1000 | 2000 | 4000 | 6000 | 8000 | 11000 |
|---|---|---|---|---|---|---|---|---|---|
| A.S | 5 | 10 | 15 | 55 | 55 | 60 | 50 | 60 | .. |
| Air— | | | | | | | | | |
| A.D | 15 | 15 | 20 | 65 | 65 | 60 | 45 | 55 | --- |

The reading at 4 000 c.p s in the Left Ear is the greater

CHIPPER

| | 100 | 250 | 500 | 1000 | 2000 | 4000 | 6000 | 8000 | 11000 |
|---|---|---|---|---|---|---|---|---|---|
| A.S | 5 | 10 | 35 | 50 | 50 | 50 | 45 | 60 | .. |
| Air— | | | | | | | | | |
| A D | 10 | 20 | 40 | 40 | 55 | 60 | 50 | 50 | — |

The reading at 4 000 c p s in the Right Ear is the greater

MACHINE HAMMER

| | 100 | 250 | 500 | 1000 | 2000 | 4000 | 6000 | 8000 | 11000 |
|---|---|---|---|---|---|---|---|---|---|
| A.S | -10 | -5 | 0 | 20 | 65 | 85 | — | .. | |
| Air— | | | | | | | | | |
| A D | -5 | 0 | 0 | 15 | 70 | 90 | | | .. |

Fig 2

*d* When there has been lengthy exposure to certain noises and the resultant hearing loss shows a fair amount of change at 1,000 c p s , and even at 500 c p s the audiometric dip at 4,000 c p s tends to level out, or even be eradicated, but the audiogram still is indicative of possible noise induced etiology (see Fig 2)

*e* Concomitant disease and presbycusis are two important causes for an eradication of a notching 4,000 c p s audiogram by causing even greater losses at the 6,000 and 8,000 frequencies Diseases and toxic conditions which may depress the hearing in this manner are syphilis, dental, tonsillar and prostatic diseases, alcohol, nicotine, quinine, the salicylates, the mycins (antibiotics), senile vascular changes, allergy, etc (see Fig 3) (Example losses above 4,000 c p s are the greatest )

PRESBYCUSIS

| | 100 | 250 | 500 | 1000 | 2000 | 4000 | 6000 | 8000 | 11000 |
|---|---|---|---|---|---|---|---|---|---|
| A S | 5 | 10 | 10 | 10 | 10 | 20 | 50 | 60 | |
| Air— | | | | | | | | | |
| A.D | 0 | 5 | 5 | 5 | 10 | 30 | 60 | 65 | |

DISEASES

| | 100 | 250 | 500 | 1000 | 2000 | 4000 | 6000 | 8000 | 11000 |
|---|---|---|---|---|---|---|---|---|---|
| A.S | 35 | 40 | 50 | 55 | 60 | 55 | 65 | 70 | – |
| Air— | | | | | | | | | |
| A D | 40 | 35 | 45 | 50 | 60 | 65 | 60 | 70 | |

ALLERGY

| | 100 | 250 | 500 | 1000 | 2000 | 4000 | 6000 | 8000 | 11000 |
|---|---|---|---|---|---|---|---|---|---|
| A S | 25 | 25 | 30 | 35 | 50 | 60 | 70 | 75 | |
| Air— | | | | | | | | | |
| A D | 30 | 25 | 35 | 35 | 45 | 60 | 65 | 70 | |

Fig 3

*f* Primarily the audiometric findings must be stable Three audiograms, each taken one week apart and at least 40 hours after the last exposure to noise, must show no appreciable variation This should be a requirement for establishing a base line for noise-induced hearing loss This practice, if adopted, rules out any temporary threshold shift of hearing This temporary threshold shift is known to exist in all involved ears during and shortly after exposure to noise Likewise, this practice will establish the persistent hearing loss present after 40 hours, from the last exposure Any change between the persistent hearing loss and a later determined permanent loss will be minimal

*g* Repeated audiograms will be important evidence in ruling out malingering or a false claim that a loss due to disease is due to noise Sometimes a single audiogram will do this (see Fig 4) (Example unilateral loss claimed to be due to chronic noise exposure) *

## PRESBYCUSIS

Presbycusis has been mentioned above as a complicating factor in interpreting audiograms when noise inducted hearing loss is suspected Some loss of sensitivity at some frequencies is to be expected as the normal result of the process of ageing This has been shown in many studies, but those of Bunch,[1] the World's Fair,[2] the San Diego Fair,[3] and the Wisconsin State Fair,[4] are in reasonable agreement as to the hearing loss which is present due to ageing It is generally agreed that hearing losses due to noise and presbycusis are additive[5] The Z24-X2 Committee of the American Acoustical Society pointed out that both presbycusis and noise-induced hearing loss are "intra-cochlear deafness" They are indistinguishable microscopically Both involve the permanent loss of some sensory cells and their nerve fibers This Committee felt there was no reason to suppose that presbycusis protects the ear from further injury by noise, nor does it make the ear more sensitive to injury

| | 100 | 250 | 500 | 1000 | 2000 | 4000 | 6000 | 8000 | 11000 |
|---|---|---|---|---|---|---|---|---|---|
| A.S | 0 | 0 | 0 | 5 | 0 | 0 | 5 | 10 | – |
| Air— | | | | | | | | | |
| A D | 45 | 50 | 60 | 70 | 60 | 50 | 75 | 80 | — |

The loss at 4 000 c.p s is considerably less than at 500 and 1 000 c.p s

Fig 4

An allowance for the loss, due to presbycusis, has been suggested for appraising the hearing loss in workers over 50 years of age For the frequency 2,000 c p s, this loss on the average amounts to about 5 db in the sixth decade, and 10 db in the seventh The losses at 4,000 c p s on the average are about 10 db and 20 db respectively, but there are large individual differences[6]

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## SUSCEPTIBILITY

That the human ear is susceptible to hearing loss by exposure to chronic noise has been known for years. Fosbroke's[7] article in *Lancet* was written 137 years ago, and this cause of hearing loss was probably recognized before this early date. How susceptible the ear may be, and whether or not some ears are more susceptible than others has been a debated subject for scores of years. The answer to the susceptibility question is relative rather than absolute. Barr[8] commented that of 100 boilermakers examined by him who had worked at this trade at least four years, none had normal hearing. Boilermaking certainly is an occupation which has a hazardous noise exposure, particularly when a worker is subjected to the reverberating sounds inside a boiler. What about less hazardous noise exposures?

Most writers on the subject of noise-induced hearing loss state that some human ears are more vulnerable than others,[9,10] but no one to date has fashioned a statistical table attempting to delineate what percentage of all ears are, for instance, highly susceptible, very susceptible, moderately susceptible, barely susceptible, etc. If one dared prepare such a table it would have to be for one certain well described and accurately measured noise, existing under known conditions, to which would have to be added the known length of exposure. It is obvious that there would have to be thousands of tables to have any value at all, for the variables are multidimensional; even then such tables would be valueless for protection purposes, for they could not delineate a particular individual and indicate that he would be one of the highly susceptibles.

There has been much searching for a reliable test for sensitivity. Everyone acknowledges its desirability, but to date none of the advocated tests have been validated by practical experience. Tests have been devised, based on marked loss of hearing immediately after exposure to loud noise[11] or on the basis of slow recovery from such a temporary threshold shift,[12,13,14,15] but persistent and *permanent* hearing losses do not necessarily follow a temporary threshold shift. Here again variables are multidimensional Like variables are present for the Lawrence and Blanchard[16] aural harmonics test for susceptibility

Glorig has stated from the examination of many thousands of industrial hearing records there are only a few persons who are highly susceptible to noise For the present, then, it seems expedient and wise to employ monitoring audiometry in all industrial situations where a noise problem exists, and to separate from their noisy environment those workers who show significant hearing losses on several 40 hours audiograms This will protect both the employer and the employees, and is a safe procedure to use till further studies and further statistics can show that a valid susceptibility test is or is not possible.

## SUMMARY

The problem of the diagnosis of noise-induced hearing loss is difficult, because losses due to causes other than noise may be present A detailed history of a patient may furnish valuable information. The examination of the patient, together with a study of his audiograms, can give further light

Presbycusis is a known complicating factor, and an allowance for its presence should be made in workers over 50 years of age

Susceptibility to noise is as yet an unsolved problem No predictive tests have been validated The answer to susceptibility is relative rather than absolute

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# EAR PROTECTION *

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Most probably, even those of you who do not take any active part in solving the noise problems must have noticed that these problems have been discussed, if not exhaustively, at least extensively at many times and at many places We have a journal entitled "Noise Control," and a "Handbook of Noise Control" Numerous committees and meetings are devoted to noise problems Possibly some of you might think that we are making too much noise about noise, however, even those who do think so must admit that, one way or the other, we do have too much noise, and that something should be done about it.

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I consider myself fortunate to have been given the opportunity of discussing one of the means of combating noise. This gives me the feeling of usefulness, of doing something positive instead of just complaining. Of course I must admit that if nobody complained about noise, and there are still some left who do, I would have no business talking about ear protection.

Now, back to the subject. I doubt that anybody considers the personal ear protectors as the most desirable means of noise control. There are probably no more people who want to wear earplugs or earmuffs than there are people who want to wear eyeglasses. Although not the most desirable, personal ear protectors are probably the most versatile, effective and the most economical means of noise control. This does not imply, of course, that other means should be happily abandoned. In many situations we have to apply every trick we know to keep noise at a tolerable level, and sometimes we run out of tricks. In addition, personal ear protectors are always somewhat uncomfortable and cumbersome, and, maybe most important, they do not improve speech communication by any considerable amount, except when the transmission occurs through an earphone, and the earphone with its socket serves as an ear protector.

The best means of noise control is undoubtedly to stop the noise right at its source. That means, not to make any noise at all. Unfortunately, we have not been very successful in this endeavor and, according to Dr. Knudsen, noise is increasing at a rate of one db. per year. It seems, therefore, that ear protectors are here to stay for a while, and they should be considered at an equal level with the other tools of noise control.

I could devote this time to showing you pictures of various types of ear protectors, but I doubt that in this way you would learn much more than the fact that there are many types of ear protectors. I shall try rather to synthesize our knowledge on the problem of personal ear protection, discuss the basic requirements, the possibilities, and the main trends in recent design

It is possible to classify the ear protectors according to their position relative to the ear We have four kinds earplugs, semi-inserts, earmuffs, and the helmet Earplugs are secured in the ear canal and usually do not require any additional means of support (see Fig 1) Semi-inserts are placed at the entrance to the ear canal and are usually supported by a headband Earmuffs cover the outer ear like an earphone mounted in its socket or cushion Helmets cover the whole head, or at least most of it

I am going to omit the semi-inserts, because there are none on the market, and the helmets, because I feel that at present they do not offer any acoustical advantage

Now, what is expected of ear protectors? *First,* they should attenuate acoustic noise to a safe level, whatever that level is *Second,* they should be comfortable, or, let us be more realistic and say, they should not be too uncomfortable *Third,* they should not have any toxic effect on the skin There are further requirements that are more or less compelling, depending on the situation They concern the interference with speech communication, the ease with which the ear protectors can be handled, the sanitary aspect and the economic aspect Some of these requirements are in conflict with each other, and only compromise solutions appear possible The best known incompatibility is between sound attenuation and comfort Another one is between attenuation and speech intelligibility, although this one is more apparent than real, but let us start with the first requirement, *i.e.*, sound attenuation

How much sound *should* be attenuated?

This is certainly a pertinent question Unfortunately, I cannot answer it, at least, not at this time, because there are probably as many optimal attenuations as there are situations in which the use of ear protectors appears advisable and maybe even more, maybe almost as many as there are people

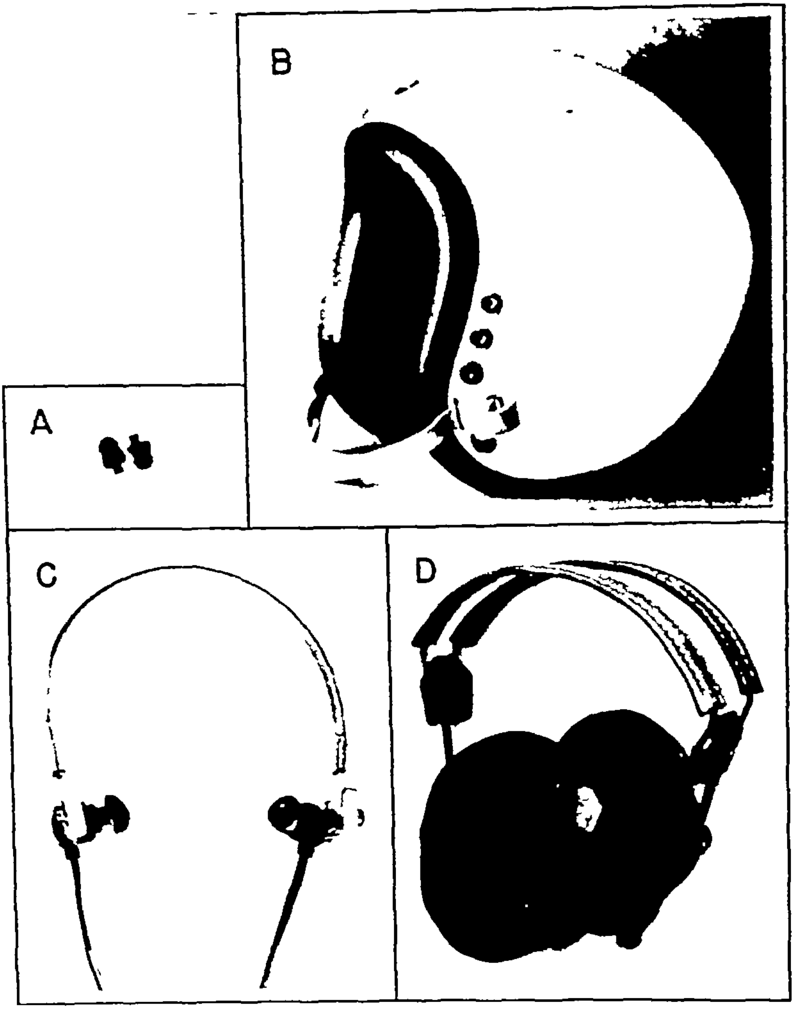


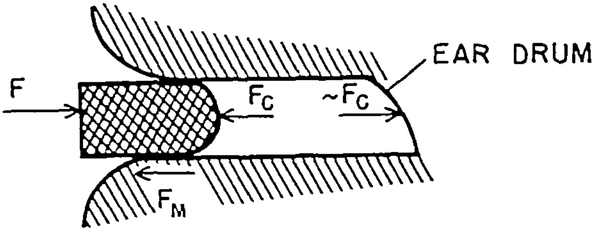
Fig 1. Four Kinds of Ear Protectors.

involved In other words, this is a policy question at present, and not a scientific question, and therefore not for me to answer I can answer, however, a somewhat related question how much sound *can* be attenuated? This question is restricted, of course, to ear protectors that can be worn either in the ear canals or on the head By enclosing a man in a cell of concrete, higher sound attenuations than those I am going to speak of can be achieved

When an earplug is inserted into the ear canal, the sound can still reach the inner ear on three pathways. Because of the flexibility of the skin lining the external auditory meatus, sound waves can produce a vibration of the earplug as a whole. The vibration is controlled at low frequencies by the stiffness and the viscosity of the skin and, at high frequencies, by the inertia of the earplug. The sound can also penetrate the ear through deformation of the earplug—here the stiffness, density and viscosity of the material become important. Finally, sound can reach the inner ear by traveling around the earplug, either via bone or via soft tissue or both. I am going to refer to this channel as body conduction.

For low frequencies, the forces acting on an earplug secured in the ear canal may be schematized as shown in Fig. 2. The force $F$ symbolizes the external sound pressure multiplied by the effective area of the earplug. The force $F_C$ is equal to the produce of the sound pressure generated in the ear canal and of the crosssectional area of the ear canal. Finally, $F_M$ denotes the resultant opposing force developed in the skin lining. The law of the equilibrium of forces requires that $F$ be equal to the sum of $F_C$ and $F_M$. It is easy to see that the sound attenuation grows with the ratio between $F_M$ and $F_C$. This ratio is determined to a large extent by the properties of the skin lining and by the volume of the enclosed air, in addition to the acoustic impedance that can be measured at the ear drum. It is, therefore, an anatomical constant and cannot be altered to any considerable degree. The only thing we can do in order to improve the sound attenuation is to make the earplug itself impervious to sound. Various solutions are possible, and I am going to discuss them a little later when I show you some typical designs.

Let us now consider the factors determining the sound attenuation provided by earmuffs. Although earmuffs look considerably different from earplugs, their acoustic action is similar. The vibration of a good earmuff is controlled by the flexibility and the resistance of the skin under the cushion, and by the inertia of the earmuff. The sound attenuation depends mainly on three factors: the mechanical properties of the skin, the mass of the earmuff, and the depth of the



$$F = F_M + F_C \;;\quad \frac{F}{F_C} = \frac{F_M}{F_C} + 1$$

$$\frac{F}{F_C} = \frac{F_M + F_C}{F_C} \;;\quad A = \frac{p}{p_C} \cong \frac{F}{F_C} \cong \frac{F_M}{F_C}$$

Fig 2 Schematic drawing of an earplug in the ear canal and the relations among the acoustic forces acting on the earplug

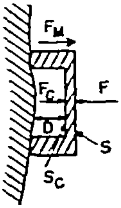
$F = F_M + F_C$

$F_M = Z_M u$

$F_C = Z_C u$

$F = u(Z_M + Z_C)$

$F_C/F = Z_C/(Z_M + Z_C)$



$F = Sp$

$F_C = S_C p_C$

$p_C/p = S/S_C \times Z_C/(Z_M + Z_C)$

$Z_C \sim S_C^2/V,\ V = S_C D$

$Z_C \sim S_C/D$

$$A = p/p_C \sim Z_M D/S$$

Fig 3 Schematic drawing of an earmuff covering the ear and the relations among the acoustic forces acting on the earmuff

earmuff The situation is described by the schematic drawing and the formulas of Fig 3, however, I do not want to go into algebra, and shall state only that, when a high attenuation is desired, the earmuff should be deep and cover as small an area of the head as possible Of course, in practice there are limits in both respects A deep earmuff becomes cumbersome, and an earmuff that covers too small an area of the head may exert painful pressure on the pinna and become uncomfortable

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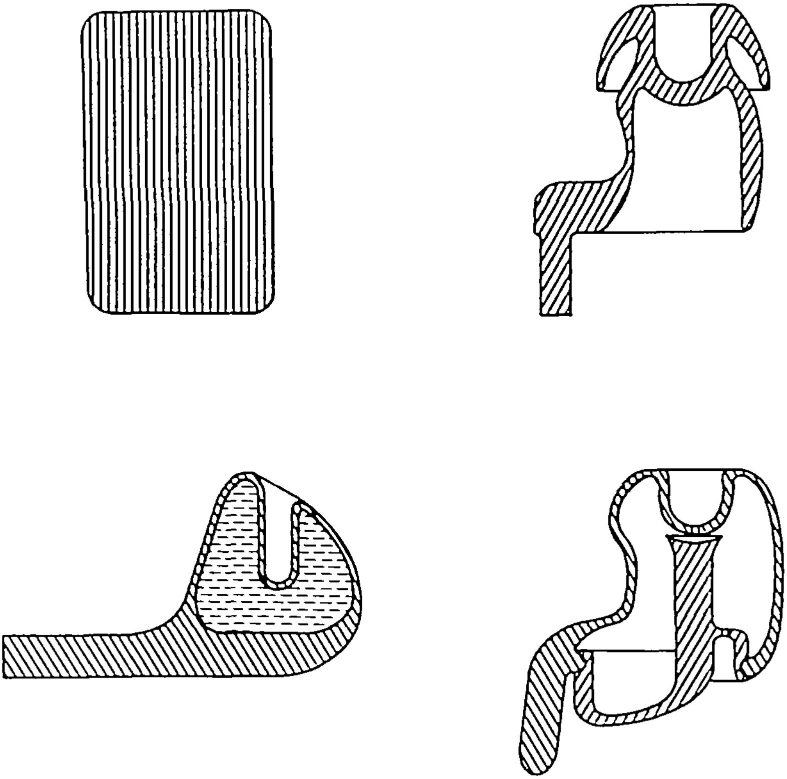

Fig 5 Four Types of Earplugs.

Regarding a few models of commercial ear protectors, Fig 5 shows four earplugs which, I think, are typical The earplug in the upper left corner is a cylinder of wax and cotton It can be shaped by hand to fit the ear canal Ear-

Even if the earplug and the earmuff were ideal in the sense that no sound would be transmitted through them, the sound could still reach the inner ear by body conduction, as I mentioned before Body conduction constitutes the absolute limit of sound attenuation that can be expected from ear protectors

The body conduction threshold in a free field has been measured recently, and I am going to report on it in the coming meeting of the Acoustical Society in New York Here I can only show you some of the experimental results

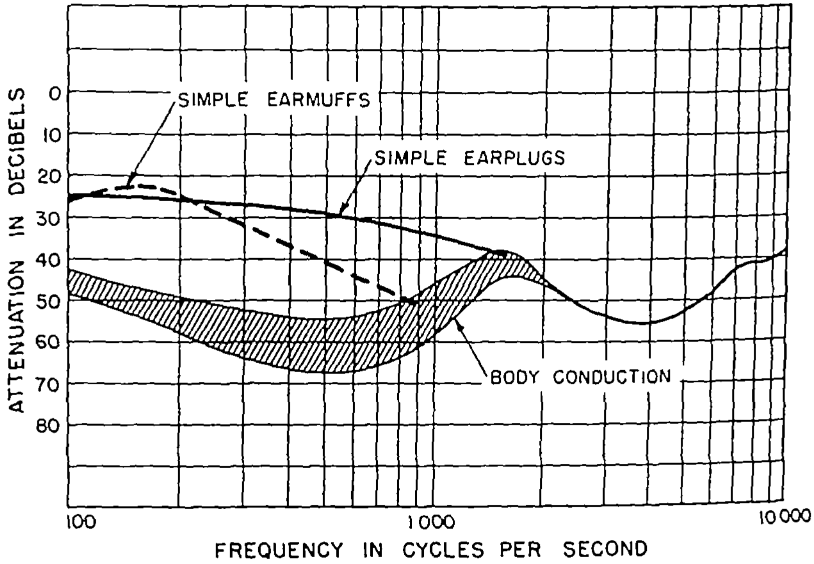

Fig 4 Air conduction (lower curve) and body conduction thresholds of audibility in a free sound field. The shaded area indicates the uncertainty due to the effect of the occlusion of the ear canal on bone conduction

The zero level in Fig 4 refers to air conduction threshold in a free sound field The lowest curve in the diagram is the body conduction threshold in a free field as measured recently The shaded area indicates the uncertainty caused by the effect of the occlusion of the ear on bone conduction It is well known that the occlusion of the ear canal improves bone conduction at low and medium frequencies when tests are per-

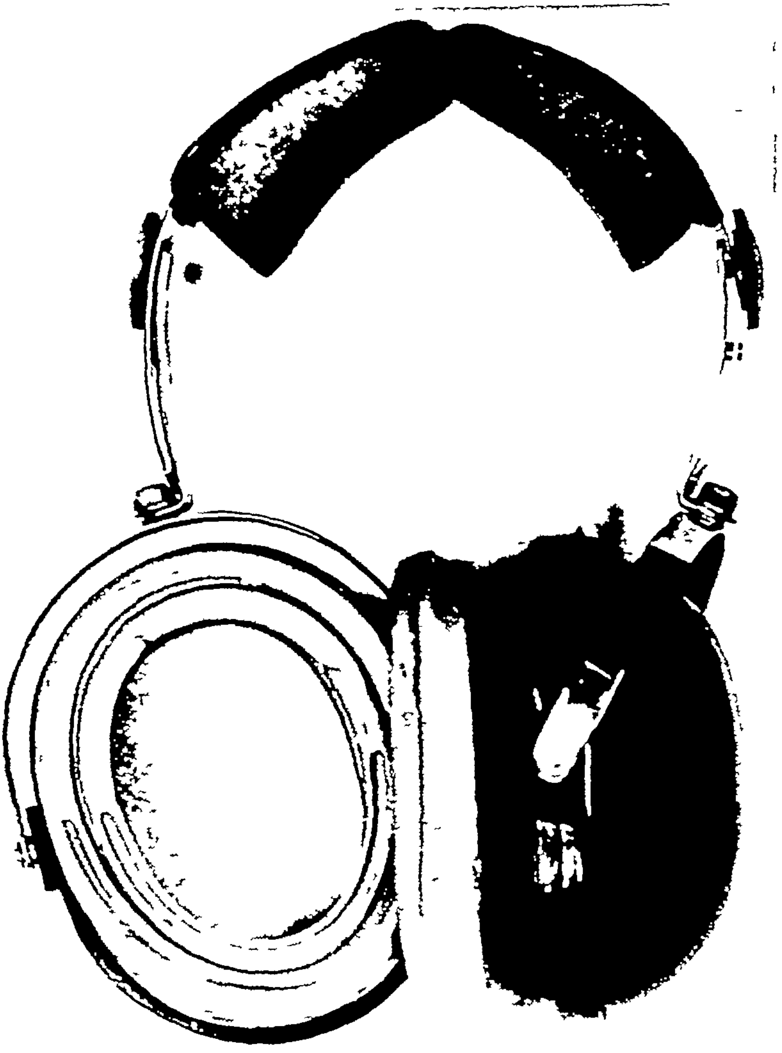

Fig 7 A Set of Typical Earmuffs.

being inserted into the ear, and facilitates the insertion by stiffening the earplug along its longitudinal axis In addition, a back wall increases the sound attenuation at high frequencies In some of the models the front and the back wall are perforated so that the earplug acts as a low-pass filter The advantages of such a decreased attenuation at low frequencies is still debated plugs of this type are very comfortable and attenuate noise pretty well They have the drawback, however, that they cannot be washed and, consequently, have to be thrown away after being used only once Their sticky surface has the tendency to accumulate dirt

The earplug in the upper right corner consists of rubber or plastic Because of its elasticity it adapts to the shape of

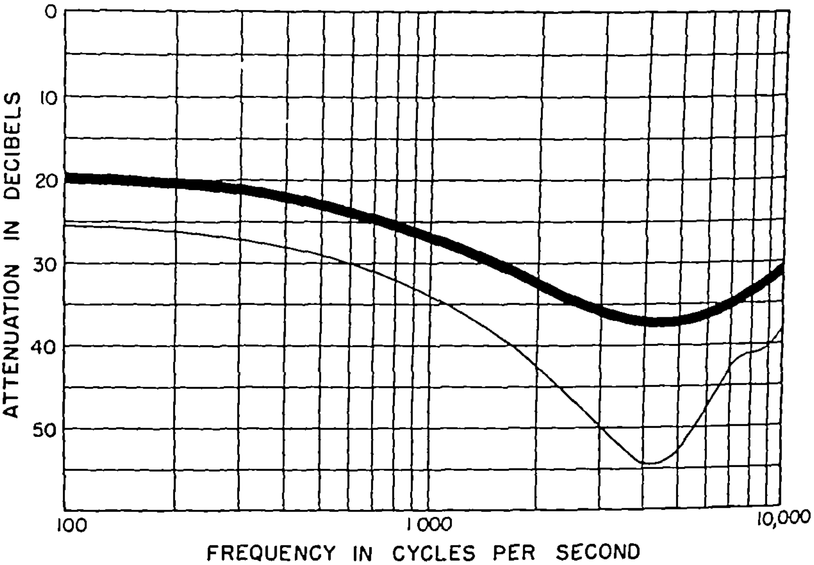

Fig 6 An approximate attenuation characteristic of the four earplugs shown in Fig 5 (heavy line) The thin line shows the theoretical upper attenuation limit for simple earplugs

the ear canal while being inserted It attenuates noise very well, is washable and can be reused many times There is one difficulty in order to obtain a high attenuation, the material of the earplug must be sufficiently stiff When the earplug is too stiff, however, it becomes uncomfortable, so that only a compromise solution appears possible

The earplug shown in the lower right corner of Fig 5 is basically similar to the earplug discussed in the preceding paragraph, but it has some additional features It contains an internal core made of a stiffer material than the outer shell This core touches the front wall while the earplug is curve shows the theoretical upper attenuation limit for simple earplugs

Fig 7 shows a set of typical earmuffs The earmuffs are designed very much along the lines mentioned above they are deep, enclose a large volume of air, cover a rather small area of the head, and consist of a hard shell and a sealing cushion of foam rubber The sound attenuation thus provided can be seen in Fig 8 (heavy line), together with the theoretical limit (thin line) The foam rubber cushion may be considered a weak point in the design of the earmuff Recently developed cushions with high internal viscosity or with low volume compressibility could further improve the attenuation at low frequencies

I would like to conclude on an optimistic note by predicting that within a few years we are going to have ear protectors which will attenuate sound up to the limit set by body conduction I hope that such ear protectors will be commercially available

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# ESTABLISHMENT OF CRITERIA BASED ON THE CONCEPT OF NOISE EXPOSURE*

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This morning we have heard a discussion of the general topic of noise-induced hearing loss Thus far the emphasis

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*This work was supported in part by the U S. Army (Signal Corps) the U S. Air Force (Office of Scientific Research Air Research and Development Command) and the U S. Navy (Office of Naval Research)

The earplug in the lower left corner is probably of the most recent design It combines some features of the wax-cotton earplugs with those of the permanent elastic earplugs It consists of a malleable core covered by thin elastic walls The internal tube, which is open at one end, increases the adaptability to the ear canal Within certain limits the earplug is malleable like the wax-cotton earplugs At the same time it has sufficient resiliency to follow temporal changes of the cross-sectional area of the ear canal It can be washed and reused

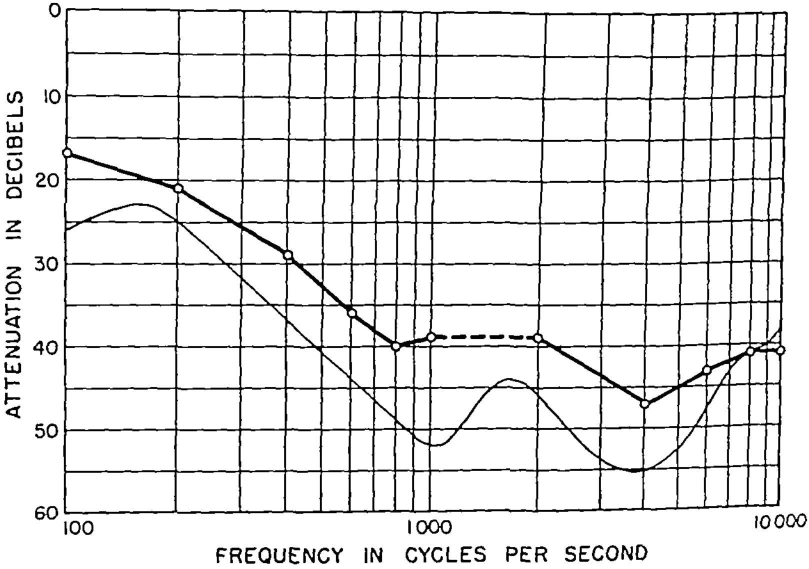

Fig 8 The attenuation characteristic of the earmuffs of Fig 7 (heavy line) and the theoretical upper attenuation limit for simple earmuffs (thin line)

All the earplugs of Fig 5 provide approximately the same sound attenuation At least, the differences among the earplugs, found in one laboratory, are of the same order of magnitude as differences in results obtained for the same earplug in different laboratories It seems reasonable, therefore, to pool the data obtained for the four earplugs The thick curve of Fig 6 was obtained in this way The thin the effects of noise upon exposed humans than we can predict the genetic effects of atomic radiation upon future generations Just because we can, under the right conditions, make fairly reliable audiometric measurements of man's hearing does not mean that we can ignore the basically multivariate and statistical nature of the after-effects of any exposure, whether this exposure be to acoustic, electromagnetic, or atomic radiation There are no convenient single numbers that summarize both the exposure and its over-all effects, and this is, to me, what Dr Hoople means when he writes "the relations of hearing loss to noise exposure are multidimensional"

### THE SEARCH FOR AN ECONOMICAL DESCRIPTION OF THESE RELATIONS

It appears, then, that we must pick and choose a set of variables in order to describe noise exposure and its effects upon the hearing of even quite well-defined exposed populations Selection of the variables is determined in part by our ability to measure certain quantities more accurately and more easily than others, in part by our value judgment of what aspects of human hearing are most important, and finally, by our desire to obtain simple relations between reasonably economical descriptions of both exposures and after-effects If these relations between quasi-engineering variables make sense in the light of what we know about possible mechanisms, so much the better

It is in this context that the progress of research on the after-effects of noise exposure and of criterion guessers must be evaluated We have come a long way since the period in which noise exposure was characterized by an over-all level, read on one of the early sound-level meters, we are, nevertheless, far from being able to give an adequate description of the acoustic environment in which a drop forger spends his working life We have become keenly aware of the fact that exposures to even quite steady-sounding noises need to be characterized by spectrum, duration, and by what might be called a statistical description of temporal fine-structure

These considerations give us a glimpse at the complexities has been upon the technical problems that still remain to be solved The speakers who preceded me stressed for our benefit the difficulties that are encountered in the collection of data and the uncertainties of interpretation that need to be resolved By way of contrast (and not with any intention of being less honest) I shall try to emphasize, in rather general terms, the knowledge that we have already gained Consensus is obviously needed before we are ready to go about setting criteria or standards realistically Unless there is significant agreement among the presumably best informed technical people we have no basis for the social standard of judgment that a criterion represents In the United States alone, several criteria have been suggested within the past decade, and the same seems to have happened in other countries This plethora of suggested criteria reflects to some extent the complexity of the task involved, whether we attempt to set standards for maximum allowable concentrations of chemical poisons, for exposure to radiation, or for exposures to noise

Recently (1956) the U S National Academy of Sciences published a series of summary reports on "The Biological Effects of Atomic Radiation " The distinguished committee on the Genetic Effects of Atomic Radiation tried to put before the general reader some of the complications that must be faced before decisions can be reached or recommendations for the general welfare made The scientist-citizen has to be willing to make rough estimates in areas in which his knowledge is far from certain He may then have to weigh the outcome of these technical considerations, with their attendant uncertainties, against considerations of national security and international relations The role of the scientific statesman is thus hardly one for which graduate or even postgraduate study prepares

## THE RELATIONS OF HEARING LOSS TO NOISE EXPOSURE INVOLVE MANY VARIABLES

Fortunately, the risks that concern us in this conference are less serious than those that result from exposure to atomic radiation, furthermore, we can more easily assess some of to these questions or at least decisions regarding them would have to be forthcoming before standards or criteria could be stated In the years that have passed, informed scientific opinion has come to feel that as long as man's hearing for everyday speech, under everyday conditions, remains protected, we are successfully preventing noise-induced hearing losses from becoming a serious handicap We have said enough about the difficulties of specifying noise exposure The last two decades have seen much progress in the spectral analysis of noise, it is to be hoped that in the years ahead comparable progress will be made in the analysis of noise exposures Certain promising beginnings have already been made, and the necessary electronic equipment and computational facilities are at least in principle available

The Z24-X2 report asked "What percentage of the people exposed should a standard be designed to protect?" This amounts to picking a cut-off percentage in a statistically determined situation and is equivalent to saying that a given criterion entails a risk of a serious handicap in X per cent of the exposed population The representative of a state government who testified before the Z24-X2 committee reminded us gently that such a position was politically impossible in a democracy, where one has to aim at protecting everybody Without entering into an argument on issues of social philosophy, let us point to the role of programs of hearing conservation and in particular to monitoring audiometry It is by such programs that the highly susceptible individuals who are working in noise-hazardous areas can be identified and transferred to locations where there is less risk to their hearing Thus criteria and preventive medicine can combine to protect practically everyone

*Two Examples of Criteria for Noise Exposure*

From what precedes it should be clear that a particular criterion represents a multifaceted compromise it assumes a certain population and a certain level of acceptable risk, it is, in general, accompanied by a certain hearing conservation program, and it makes certain assumptions about future noise exposures (most often it assumes that they will be more or less identical with those that prevail today) By of defining the effective exposure stimulus Its specification depends, at least in part, upon the kind of after-effect in which we are going to be interested, hence, we need agreement upon a valid and yet reliably measurable estimate of man's auditory capacities Given our general concern with human communication, it seems reasonable to settle upon man's ability to communicate by speech This is not the place to discuss our present ability to make such measurements in a nonlaboratory environment, or even the possibility of predicting, by pure-tone audiometry, man's ability to discriminat speech, but we should emphasize that pure-tone audiometry will continue to have value from the viewpoint of preventive medicine for a long time to come

Finally, we must face the problem of just how homogeneous our populations are with respect to exposure and to the variety of other variables (such as military service, education, and so on) that are at least partially correlated with the response variables that we have chosen

The socially necessary task of predicting the effects of exposure upon whole populations bears little resemblance to prediction in the classical stimulus-response paradigm There the stimulus is something that happens "here and now", it can be assumed that the experimenter has been able to uncouple his subjects sufficiently from their distant and recent past and that post-experimental events will have little influence upon the subject's response behavior Even in classical psychophysics these assumptions are not always justified, here, they are completely unrealistic Here, noise exposure stretches over a man's working life-time and may well include significant contributions to this exposure from his military service, from his acoustic environment while he travels to his job or about this globe, and from his addiction to loud music—to name just a few of the possible hazards These uncertainties in the specification of the exposure make for increased variability, just as presbycusis and quasi-social factors do

## WHOM SHOULD CRITERIA BE DESIGNED TO PROTECT?

In the section entitled "Conclusions" the Z24-X2 report formulated three questions The committee felt that answers basis for a nomogram that permits the computation of equivalent exposure times

Let us now pass from this example (in which we deal with a rather well-defined population, in which we are preoccupied primarily with "jet-type" noise, and in which the statement of criteria is accompanied by a well-designed hearing conservation program) to a document that aims at less clearly defined situations In its recent "Guide for Conservation of Hearing in Noise" the Subcommittee on Noise in Industry states

"At the present time our knowledge of the relations of noise-exposure to hearing loss is much too limited for us to propose safe amounts of noise-exposure We can, however, point to certain noise levels that indicate when it is advisable to initiate hearing conservation programs These levels will not be general because a different level is needed for different types of noise and different schedules of exposure The hearing conservation level that we now specify tentatively applies only to years of exposure to broadband steady noises with relatively flat spectra It does not apply to short exposures, and, above all, it does not apply to impact noises or narrow-band noises This tentative hearing conservation level is stated as follows

"If the sound energy of the noise is distributed more or less evenly throughout the eight octave bands, and if a person is to be exposed to this noise regularly for many hours a day, five days a week, for many years, then if the noise level in either the 300-600 c p s band or the 600-1200 c ps band is 85 db the initiation of noise-exposure control and tests of hearing is advisable The more the octave-band levels exceed 85 db, the more urgent is the need for hearing conservation"

These two statements are not unlike in philosophy and general approach, and they do not differ much in terms of the actual numbers that are involved, but it would be unwise to conclude that 85 db is "it," and that there is not room for different compromises, for different cuts of the criterion-pie If your situation permits you to "fix" other aspects of noise exposure you may want to state your criterion in minutes per making all of these assumptions as explicit as we can, we cut the number of variables to the point where criteria can be set merely by specifying a few numbers*

Now I should like to quote from two recent documents to illustrate some of the points that have been touched upon In October, 1956, there appeared an Air Force Regulation entitled "Hazardous Noise Exposure" Its purpose was to establish a program for minimizing the undesirable effects of exposure to noise on Air Force Personnel In the section of the Regulation that deals with methods of controlling exposure to hazardous noise, "limits for noise exposure" are stated in this manner

"*a Limits for lifetime exposure* The limits for lifetime exposure to broad band noise are given in terms of the band pressure level for four octave bands The four octave bands are 300-600 c p s , 600-1200 c p s , 1200-2400 c p s , and 2400-4800 c p s In setting limits, it is assumed that the ears are unprotected and exposed continuously during normal work-hours over a period of 25 years The risk of damage to hearing is slight when the pressure level of a band does not exceed 85 db It increases as the band pressure level increases, and is excessive at 95 db Ear protection is recommended for continuous exposure to a sound pressure level above 85 db in any of the four octave bands It is mandatory for exposure above 95 db Ear protection may consist of reducing the noise level in the ear canal, reducing exposure time, or both"

There follows a statement on daily short-term exposures in which the so-called equal energy assumption† serves as a

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*As a matter of fact as long as the spectral and temporal character of noise stays in sufficiently narrow bounds two different exposures of equal duration could be compared on the basis of a single number only This single number (which could be the over-all level) carries along with it a whole host of hidden parameters

†According to this concept equal quantities of acoustic energy entering the ear canal are equally injurious regardless of how they are distributed in time assuming that the equivalent quantities of noise energy equal or exceed the hearing damage risk criteria. This is not the place to examine the evidence for this assumption or to discuss the ways in which it should be qualified At present it represents within certain limits a simple and yet quite conservative guide-line It would furthermore be instructive to compare and contrast the rationale for this assumption with the rationales expressed in statements from the NAS-NRC summary reports according to which the total dose of radiation is what counts this statement being based on the fact that the genetic damage done by radiation is cumulative and The concept of a safe rate of radiation simply does not make sense if one is concerned with genetic damage to future generations

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PROF ROSENBLITH We will now have the discussion If you have a discussion as to a specific participant in this morning's program, direct it to him, if not, I shall try to direct it to the person most appropriate

DR. WARREN H GARDNER, (Cleveland, Ohio) I have been interested in the statement about the 4000 frequency dip and the probability that the dip can relate to acoustic trauma I am familiar with the audiograms of perhaps 200,000 to 300,000 children, and I have found quite a large number of 4000 frequency dips in children from ten to 18 years of age I should like to raise the question In an adult of 35 years of age, who has been working in a noisy place, how can we tell whether that 4000 frequency is due to acoustic trauma or whether he had that dip when he was 12 years old

PROF ROSENBLITH Will someone volunteer to answer?

DR SENTURIA I think Dr Hoople said something very wise about this precise problem in his paper

PROF ROSENBLITH Would you like to repeat them, or express your opinion?

DR SENTURIA No, I would like to express the opinion of Dr Gardner, that there are many persons under the age of 21—those who have not been exposed to noise, and who show 4000 cycle dips, and I, too, would like a further elaboration of this problem I wish that Dr Hoople were here, but since he is not, I would ask someone else in the audience, perhaps Dr Glorig, to elaborate

DR GLORIG I happen to be one of those persons who do not believe that there is a characteristic noise-induced audiogram It just so happens that when you look at audiograms of persons exposed to noise, the loss occurs first at 4000 cycles, day, or as a circle of yellow paint around a particular noise source, or even as a single number on the dial of a noise-level meter that weighs the frequency spectrum in an appropriate way

In summary, I should like to emphasize that, at present, we base our criteria on the concept of *noise exposure* in contradistinction to the previously emphasized *noise level* We feel that criteria or standards are, in the nature of things, a "package-deal" a given level of risk for a population whose age-structure, health conditions, and "working lifetime expectancy" in a given noise environment are more or less known, is coupled to hearing conservation and noise control programs of specified scope This ensemble of somewhat uncertain conditions is then held against the Z24-X2 trend curves (or similar information), the facts of speech communication, and against the backdrop of a prevailing social philosophy This is the process that yields criteria Men of science often feel ambivalent about their role in this process more than their nonscientific fellow-citizens, they are aware of the incompleteness of the technical information available, they know that by combining criteria with conservation programs we may protect human hearing at the cost of studying the after-effects of noise exposure more carefully, yet, if those who have expert knowledge will not advise in policy-making, they will fail to make their contribution to the functioning of a democratic society

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as just a guess, such as I have heard many times in court procedure, where the man was exposed to noise for five minutes "This is capable of producing a hearing loss, therefore, this man's hearing loss is due to noise" It is a great mistake to do this sort of thing You get yourself backed up in a corner many times, and can be made a fool of by the attorneys in this respect I don't think test of recruitment will give you any final answer

PROF ROSENBLITH Not being a medical person, may I say something about the way we have approached this problem We have talked here this morning about proability tables of hearing loss for given noise exposures Just as in mortality tables, there will be people who die early and people who die later, so for a given noise exposure, there will be a wide spread, and in this particular thing, you cannot, in my opinion, predict, unless you have a lot of extra knowledge Just as a hearing conservation program is also part of a diagnosis, because, in order to make a diagnosis, you want to have the kind of information that comes from controlling a man's hearing under conditions of noise exposure but I do not think that because there is a dip there, you can say it is noise-induced I think the answer to your question is, does it exist prior to it, whether you get an initial audiogram and then have an audiogram to follow, which will indicate what was there before the noise exposure

Prof Rosenblith The only time this morning that somebody talked about acoustic trauma was in connection with short exposures that give rise to something that we feel is more adequately described as trauma The slow, insidious, noise-induced hearing loss that we usually talk about, we would not like to confuse, at least in our present state of ignorance, with what is known as acoustic trauma Now, this is a preference, this terminology, but it helps us to keep our very limited number of facts straight

Dr Richard E Marcus, (Winnetka, Ill ) In discussing the question of differential diagnosis, as raised in Dr Hoople's paper, and brought up again in the question of the 4096 dip, I wonder whether we might not consider some of these hearing conservation programs and screening surveys In essence we are finding the number of persons who have a hearing loss Then, we must use them as a point of departure for the individual hearing test, including the pure-tone audiometry, plus recruitment tests, and whatever other test we may be able to devise, to make the differential diagnosis The contour of the audiogram itself is not an indication of the diagnosis, but other hearing tests may well give us the clues that we are looking for

Dr Glorig I believe, that if you are going to make a differential diagnosis, you must have more than hearing tests You need physical examinations and history, particularly history of occupation I find that one of the facts most lacking in the histories that are taken in noise-induced cases is the history of the occupation of the individual This, then, allows for not having sufficient noise exposure, or no knowledge of what kind of noise exposure The making of a differential diagnosis is a difficult procedure and needs a great deal of experienced judgment on the part of the diagnostician It could not be done at the flip of a finger and hearing side by side with the sense of seeing What we learn from the study of vision can sometimes clarify our study of audition, and vice versa

The particular problems I shall discuss relate to the manner in which the eye and the ear respond to the intensity of light and sound

## ELECTRICAL EFFECTS

Both the eye and the ear are what we call transducers, they convert energy from one form into another Although their principal function is to convert light and sound into nervous energy, they are also able to perform other interesting transformations Both these sense organs convert the energy of their respective stimuli into electrical energy, as demonstrated by the "electro-retinogram" in the eye and the "aural micro-phonic" in the ear These electrical phenomena turn out to be far more complex than was first supposed, but since we now know how to amplify and record the minute electrical potentials generated in the sense organs, we can use these potentials to study the action of the sensory transducers In the expert hands of my colleague, Dr Békésy, these methods have revealed important facts about the "electro-anatomy" of the complicated structures in the inner ear

Not only do the sense organs turn light and sound into electricity, but when we pass electric currents through these organs a sensation results Volta discovered this fact back in the year 1800, when he first connected some of his newly invented electric cells to metal rods inserted in his ears Some time later, E H Weber did a similar experiment, using his brother as the subject, but when he passed a current through the head, his brother saw a light This may have been the first instance of the production of what we now call a phosphene Actually, these early experiments were not very successful Fairly high D C voltages were used, and the result was too painful to bear repeating With smaller A C voltages it is quite possible to make a person hear a tone, or even a radio program I once filled my ear with salt water and connected the output of a radio set to an electrode immersed

# CONTRIBUTED PAPERS

## SESSION A

May 14, 1957

# SOME SIMILARITIES BETWEEN HEARING AND SEEING*

S S STEVENS,

Harvard University,

Cambridge, Mass

One of the most vital and interesting facts about human beings is that they are equipped with sense organs through which they keep in contact with the world around them We perceive our environment through our sensory receptors, especially through our eyes and ears, and it is difficult to conceive how the human race could survive if we had no eyes or ears to inform us of what is happening at a distance These sense organs are small in size, but important in function They are so important that we organize great scientific efforts to study their nature and their behavior, and we come together in international conferences to tell of our discoveries, and to discuss our many unsolved problems

As members of this Conference we are, of course, more concerned with the ear than with the eye, but since these two organs constitute our principal means of perceiving the energy that is transmitted to us from distant objects, the eye and the ear have much in common and since, as scientists, we are deeply interested in the general laws of nature, we sometimes find it highly instructive to study the sense of

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hearing, the basilar membrane moves through a minute amplitude which is even less than the wave length of X-rays

Calculations reveal that the minute displacements needed to excite a sensation of hearing in a good ear are of the same order of magnitude as those that are produced by the thermal agitation of the molecules of the air itself To the ear with superior hearing, therefore, we may assume that any further increase in sensitivity would be of little use, unless one cared to listen to the banging of the molecules Like the eye, the ear can perceive almost as small a stimulus as nature can produce

## DYNAMIC RANGE

Although, in evolving these transducers with their superb sensitivity, nature has pushed the thresholds down to where they are limited by the characteristics of the stimulating medium, nature has not forgotten that useful sense organs must also respond well to high intensities The dynamic range of the intensities to which these organs react is greater than a trillion to one

In order to measure such extreme ranges of energy, we commonly resort to the use of logarithmic scales, of which the decibel scale is an example We are all familiar with the use of decibels for the measurement of sound intensity, but it is interesting to note that the decibel is equally useful as a measure of light intensity By choosing appropriate reference levels, we have set up a common decibel scale for both light and sound in such a way that interesting similarities between the two senses are at once apparent [8]

The common decibel scale is shown in Fig 1 The reference or zero db levels are $10^{-10}$ Lambert for vision and $10^{-10}$ microwatt per square centimeter for audition Both of these reference levels are near the absolute thresholds of the two senses

First, we note that the luminance of the sun, our major source of illumination, is about the same number of decibels above threshold as is the intensity of a jet airplane with afterburner, which is probably the loudest sustained man-made noise yet produced Listening to the noise of such an airplane in the liquid I was able to hear the program, but it was quite distorted until a D C voltage was simultaneously applied to the electrode, then the speech and music became very clear My first thought was that this method of exciting the ear, which I have called the electrophonic effect, might prove an aid to the hard of hearing, but we soon discovered that an electrical stimulus becomes painful before it becomes loud enough to be useful When this sort of experiment is carried out on a normal ear, with an intact eardrum, the electric current probably does not excite the inner ear directly, but merely sets up audible vibrations in the skin[5]

In order to excite the cochlea directly, it is necessary to use a patient whose eardrum has been removed We once investigated 20 ears that lacked tympanic membranes[6] When stimulated by a sinusoidal electric current, 11 of these ears heard a pure tone, indicating that we may have been stimulating the cochlea directly Seven of the ears heard only a noise We may interpret the hearing of a noise as the sinusoidal current stimulating the auditory nerve directly In these experiments we sometimes stimulated other nerves—the facial nerve and the vestibular nerve—even though we were trying not to do so

## SENSITIVITY

One of the most amazing things about our sense organs is their sensitivity The eye is such a sensitive device that the minimal energy that must reach the retina in order for a man to see is a mere half dozen quanta If the eye were much more sensitive it would probably do us little good, because light energy does not come in smaller than quantal packages

The sensitivity of the ear is no less surprising The ear is the most elaborate mechanical system in the human body At those frequencies where this complex mechanism is most sensitive, a sensation of hearing is produced when the eardrum moves through an amplitude that is less than the diameter of a hydrogen atom Under these circumstances, the motion of the basilar membrane is even less than that of the eardrum—approximately 100 times less At the threshold of

## THE MEASUREMENT OF SENSATION

Although we use decibel scales to measure the intensity of the stimulus, we must realize that the decibel is not a measure of the sensation produced By this I mean that a stimulus at 50 db. does not appear to us to be half as great as a stimulus at 100 db It seems much less than half as great The law that governs the apparent growth of sensation is not the logarithmic law that Fechner proposed more than a hundred years ago If Fechner's law were correct, both brightness and loudness would be proportional to decibels But when a person is asked to compare 50 db with 100 db he nearly always says that the 50 db stimulus looks, or sounds, much less than half as strong Most people report that the 50 db stimulus appears to be only about one-fiftieth as great as the 100 db stimulus

During the years we have performed many different experiments to try to determine more precisely the law relating the magnitudes of the sensations of light and sound to their respective stimuli Although different procedures give slightly different results, certain general principles are becoming clear It is clear that we must replace Fechner's logarithmic law by a quite different formula, for the basic psychophysical law turns out to be a *power function* For example, when people are asked to make direct quantitative estimates of the subjective brightness of a white light, the magnitude of their estimates is roughly proportional to the cube root of the physical intensity, and to me a most remarkable fact is that approximately the same law appears to hold when people are asked to judge the subjective loudness of a "white noise"

In order to fix a unit for the subjective scales which we use to measure brightness and loudness, we have chosen the stimulus level of 40 db (see Fig 1) Thus we define a *bril,* the unit of subjective brightness, as the brightness one experiences when looking at a luminance of 40 db, with the eye dark-adapted Similarly, the unit of subjective loudness, the *sone,* is the loudness of a 1000-cycle tone at 40 db (40 phons) On this scale, a loudness of 2 sones sounds twice as great as a

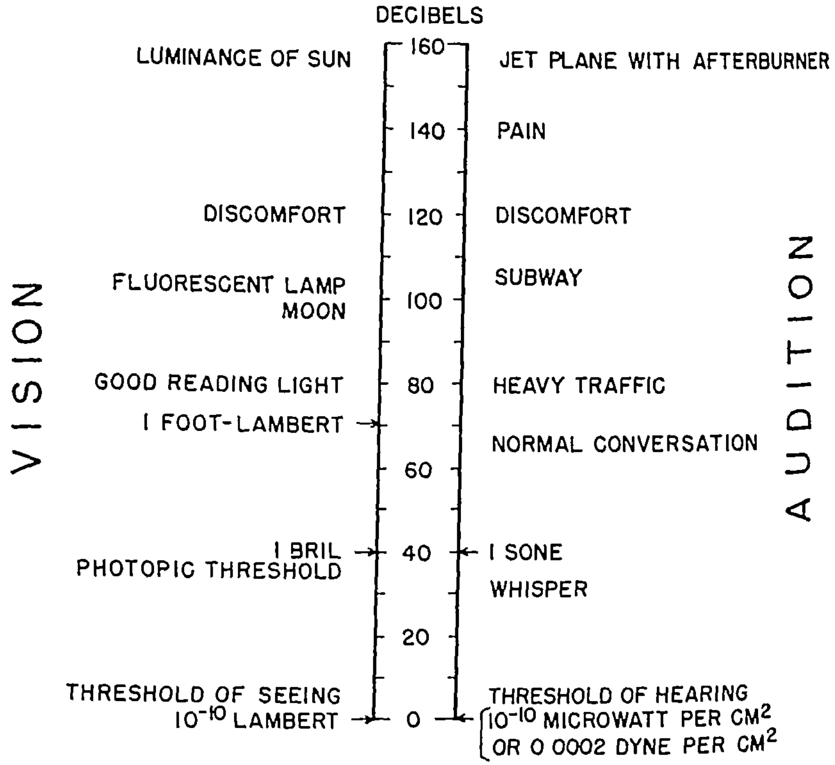

Fig 1 A decibel scale for light and sound showing the approximate levels of luminance and of sound intensity produced by various sources together with a few important threshold levels The points indicated by arrows are exact levels fixed by definition The other levels are approximations only

is hard on the ears, just as looking directly at the sun is hard on the eyes Both are far above the level where discomfort begins, which is at about 110 to 120 db on both scales The comfortable brightness for seeing and the comfortable loudness for listening are both near the middle of these decibel scales, and when stimuli are less than about 40 db we strain to perceive them

These decibel scales demonstrate that the dynamic ranges of vision and audition are enormous The sense organ processes that turn physical energy into nervous energy are such that the output of the sense organ grows with the input over a range of the order of 150 db In this respect, our sense organs are probably superior to any man-made transducers yet devised

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For a 1000-cycle tone, the standard reference signal whose sound pressure level we use as the yardstick to measure loudness level in phons, the rule is roughly the same. From the pooled results obtained in several different laboratories we have determined that the loudness in sones *S* is related to loudness level in phons by the formula

$$\log S = 0.03P - 1.2$$

This formula tells us that in order to change loudness by a factor of two we need to change the stimulus by 10 phons.[9]

The approximate similarity between loudness and brightness is shown in Fig. 2. In both experiments we merely asked observers to assign numbers to the various stimuli (presented in irregular order), and to try to make the numbers proportional to the apparent loudness or the apparent brightness. The brightness experiment was conducted by J. C. Stevens. The fact that the data fall on straight lines in a log-log plot shows that both loudness and brightness are proportional to the stimulus intensity raised to a power.

What we learn from all this is that the loudness heard by a normal ear does not bear a simple one-to-one relation to sound energy, nor to sound pressure, nor to decibels. What we perceive is a sensation resulting from the complex action of the ear and the nervous system, acting as transducers in a manner we do not yet fully understand.

## RECRUITMENT

Let us now discuss another similarity between vision and audition. It concerns the problem of recruitment, a subject of great interest to audiologists. In its extreme form, recruitment is a striking phenomenon, because an ear that shows recruitment may be hard-of-hearing for faint tones and yet hear loud tones with the same loudness heard by a normal ear. In other words, as the intensity is increased, loudness grows more rapidly in some ears than in others.

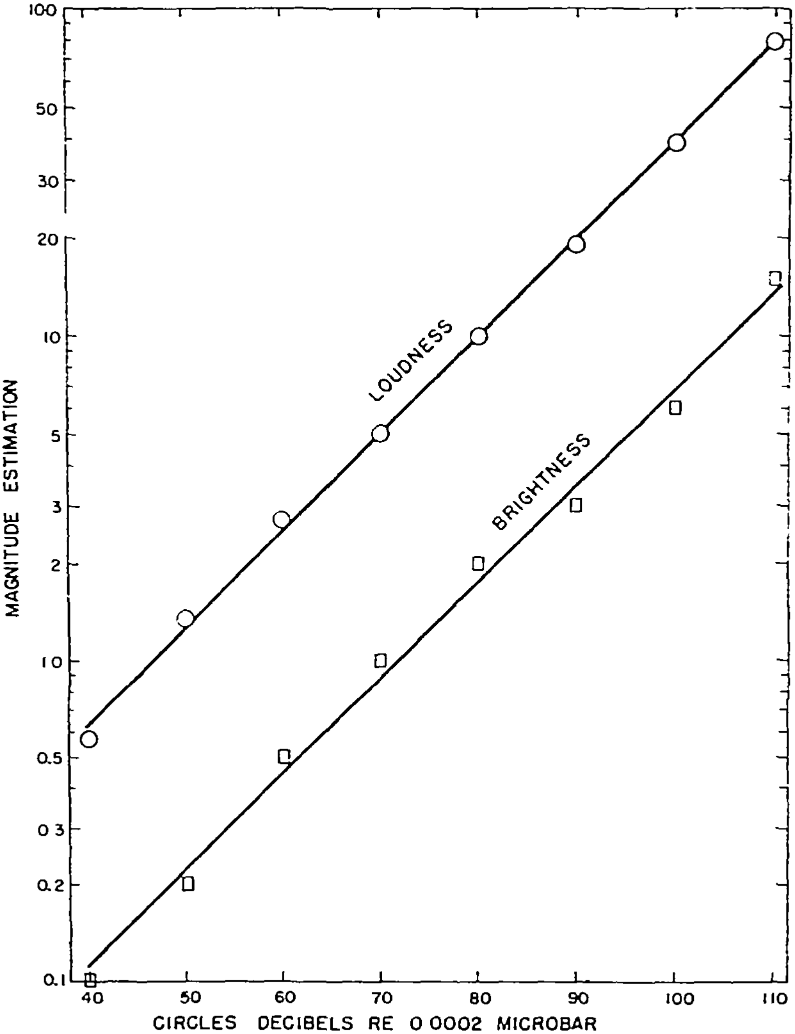

Fig 2 Median magnitude estimations for loudness and brightness For loudness each of 32 observers made two estimates of each level of a 1000-cycle tone For brightness each of 28 dark-adapted observers made two estimates of each level of a white light The target subtended a little less than 5 degrees and was illuminated for about three sec. at each presentation. The two sets of data have been separated vertically by an arbitrary amount. Hence the ordinate scale is relative only

Actually we can distinguish at least four ways in which the rate of growth of loudness with intensity can be altered All four of these are sometimes referred to as recruitment They are as follows

1 *Recruitment as a function of frequency* The loudness of low-frequency tones grows more rapidly than the loudness of high-frequency tones Thus, when a tone of 50 cycles per second is only 30 db above threshold, it may sound as loud as a 1000-cycle tone that is about 50 db above threshold

2 *Recruitment under masking* The presence of a masking noise raises the threshold for a tone, but when the intensity of the tone is raised above the masked threshold, the loudness of the tone grows rapidly When the intensity of the tone is raised sufficiently far above the masked threshold, the tone sounds as loud as it would sound if no masking noise were present

3 *Recruitment under fatigue or adaptation* Exposure to a loud noise may temporarily raise the threshold of the ear by as much as 60 db or more In an ear suffering from such a temporary hearing loss, loudness grows more rapidly with intensity than in an ear that has not been fatigued by a loud sound

4 *Recruitment in pathological ears* There are diseases of the ear that can cause hearing losses for faint tones without greatly impairing the loudness perception of intense tones We know that this kind of recruitment exists, but we still have much to learn about its causes

What concerns us here, however, is not so much the causes of recruitment as the fact that analogous phenomena occur in vision This is an important fact which we should keep in mind when we are tempted to theorize about the mechanisms underlying recruitment The phenomenon is by no means limited to the auditory sense

Each of the four classes of recruitment which we have already discussed has its parallel in vision Let us consider each of them in turn

1 As is true for loudness, brightness varies with intensity

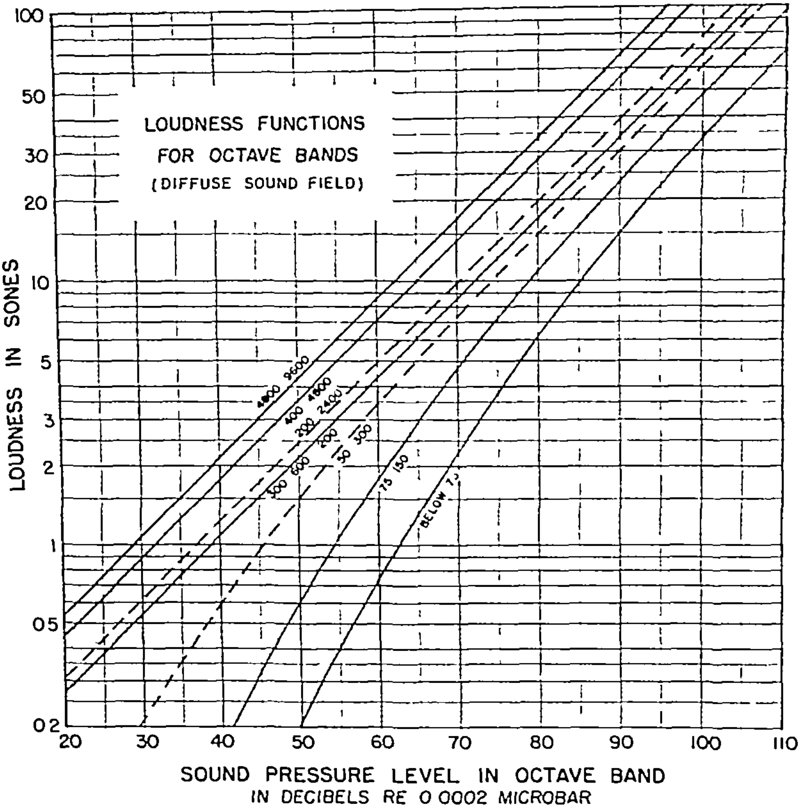

Fig 3 The relation between loudness and sound pressure level for octave bands

more rapidly for some wave lengths than for others Thus a red light appears to grow brighter at a faster rate than does a green light when the intensity is raised above threshold

These basic facts are shown in Figs 3 and 4 Fig 3 shows how the loudness of various octave bands of noise grow with sound pressure level This chart was prepared to facilitate the calculation of the total loudness of a noise on the basis of octave-band measurements[10] The total loudness turns out to be the loudness in sones of the loudest octave band plus 30 per cent of the sum of the loudnesses in all the remaining bands

The rapid growth in the loudness of the low-frequency

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1 As is true for loudness, brightness varies with intensity

threshold of a tone, but as the level of the tone is raised its loudness soon reaches the value it would have if the masking noise were not present[2] In Fig 6 we see that a very similar effect takes place in the eye Bright glare patches were placed beside a stimulus target viewed with one eye, and the brightness of the target was matched by a target in the other eye,

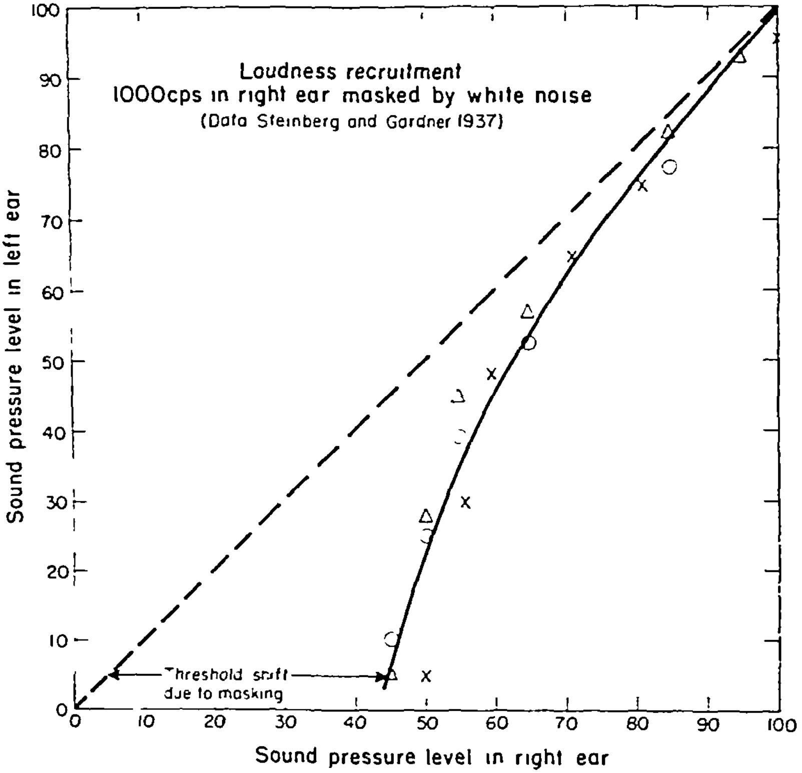


Fig 5 Loudness recruitment under masking

which was not subjected to glare The unfilled points are from an experiment by Diamond[3] The filled points show our attempt to complete the curves by determining the threshold shift under the same stimulus conditions

*3* We have also found that in the eye that has been exposed to a strong light brightness grows more rapidly with intensity bands in Fig 3 has a rough parallel in the rapid growth of the luminance of red light (650 m$\mu$) shown in Fig 4 *Luminance,* when measured in decibels, is analogous to our concept of *loudness level,* and is proportional to the logarithm of the subjective brightness The data in Fig 4 are from estimates made by Weaver[11]

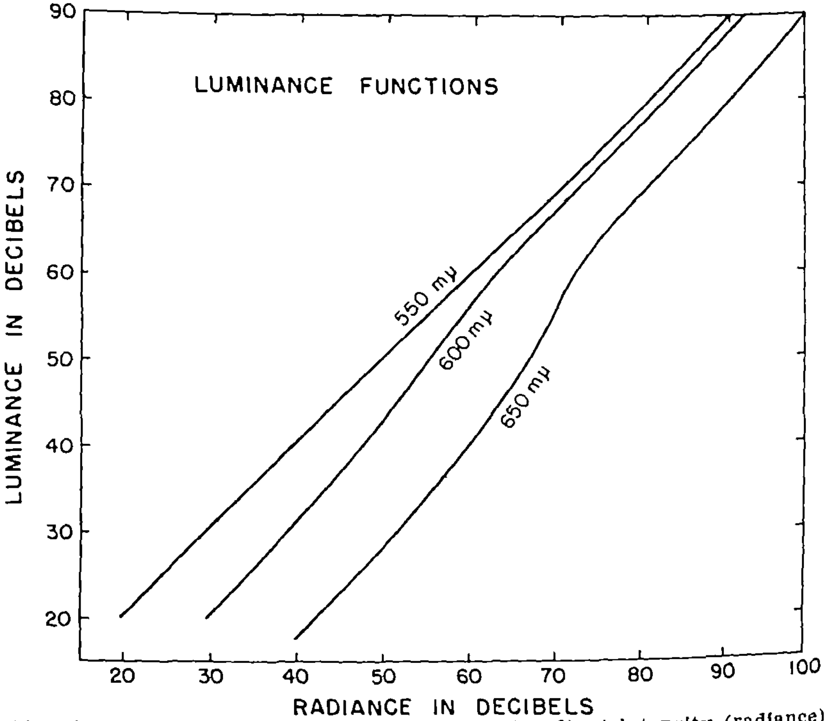


Fig 4 The relation between luminance and radiant intensity (radiance) for three different wave lengths of light ranging roughly from yellow to red

*2* Masking in hearing has its analogue in what is called *glare* in vision In the presence of a source of glare, the absolute threshold of the eye is raised, but when the stimulus is made more intense than the glare the apparent brightness of the stimulus grows to the value it would have even though the glare were not present Thus *masking* recruitment occurs in both vision and audition

Recruitment curves under masking and glare are shown in Figs 5 and 6 As shown in Fig 5, masking raises the shown in Fig 7 was obtained by exposing one ear to a wide band of noise for 32 minutes at a sound pressure level of 130 db[2] Loudness balances were then made between the exposed and the normal ear at five frequencies between 1000 and 1700 c p s The points in Fig 7 represent the averages for the five frequencies We see that, although the threshold was

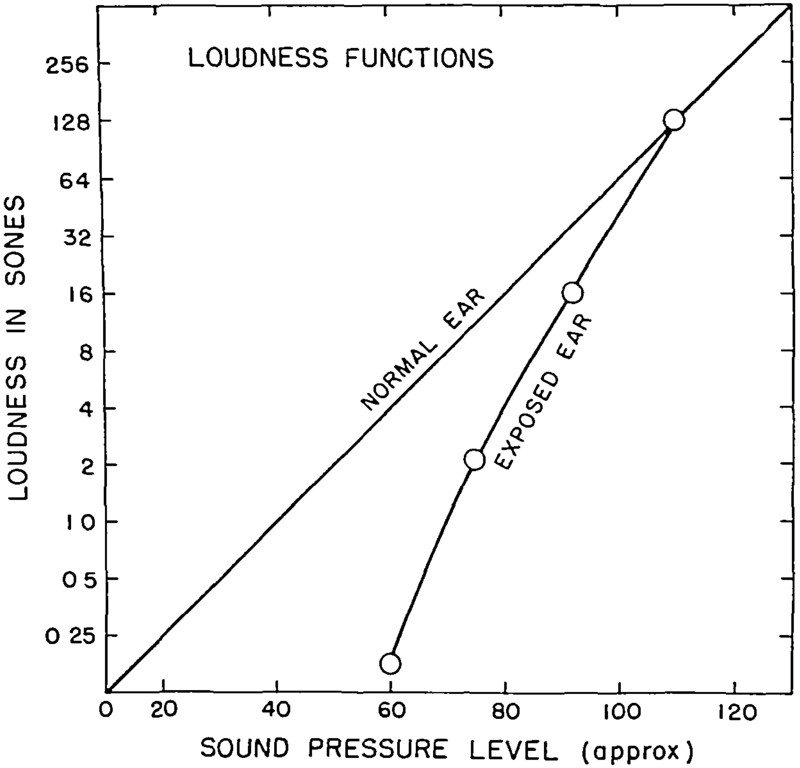


Fig 7 An example of a temporary hearing loss produced by exposure to an intense noise The exposed ear shows loudness recruitment

raised by the noise exposure, the loudness heard by the exposed ear was essentially normal for tones at an SPL of about 110 db

The effects of exposing the eye to bright light are shown in Fig 8 These data show that over the low luminance levels the light-adapted eye shows recruitment, *i e*, the curves are than it does in the eye that is dark-adapted Exposure to strong light raises the absolute threshold of the eye in much the same way that exposure to intense sound raises the threshold of the ear There are many important differences here, but in both cases the perception of intense stimuli remains more nearly normal than the change in threshold would lead us to expect In other words, brightness recruitment occurs in the light-adapted eye, just as loudness recruitment occurs in the ear that has been temporarily fatigued

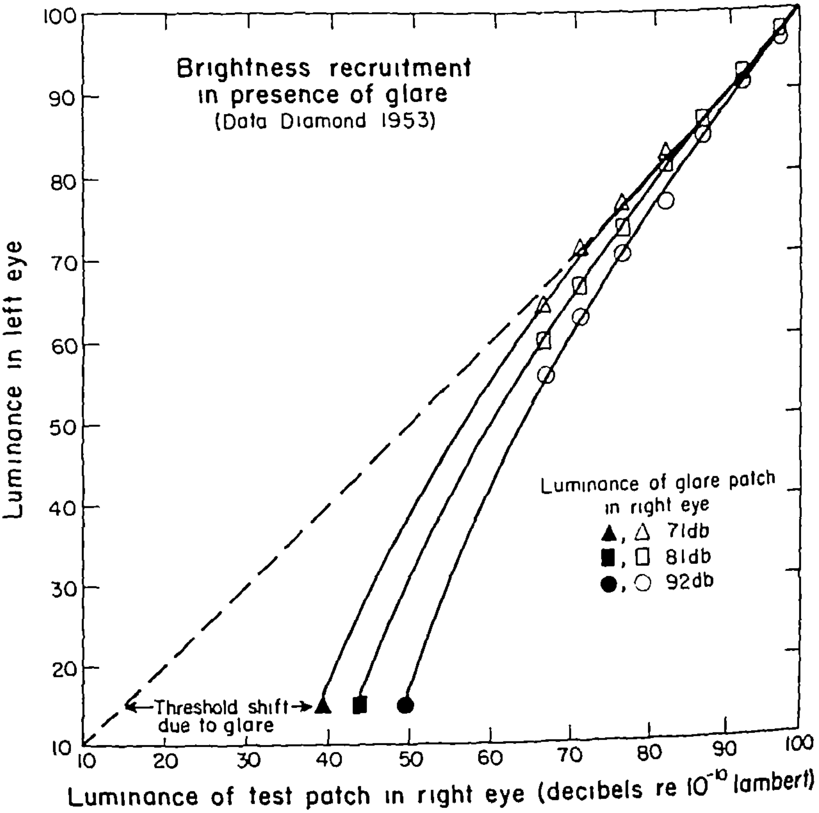
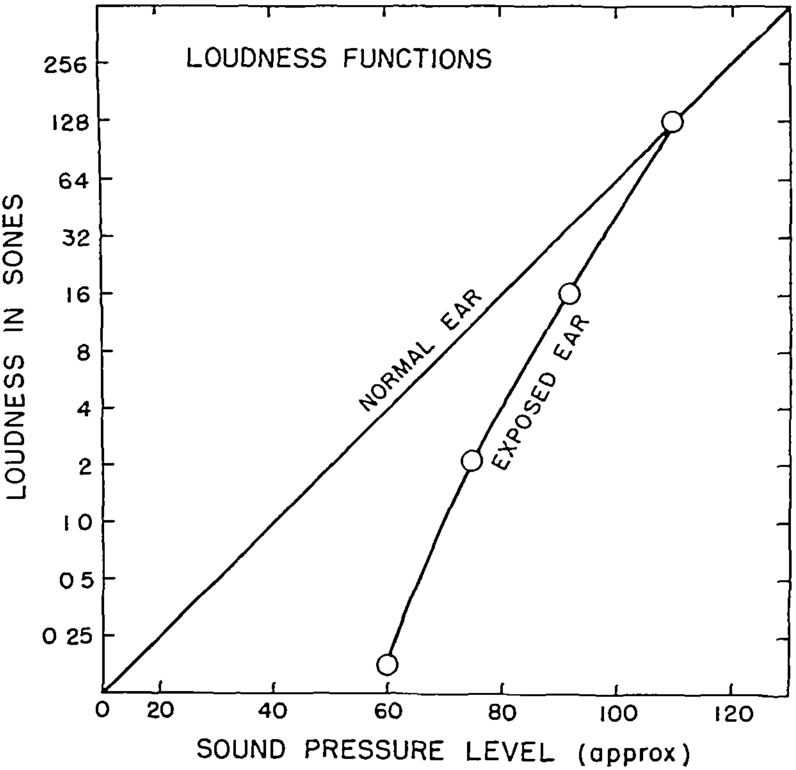


Fig 6 Brightness recruitment under glare

These relations are shown in Figs 7 and 8 Actually the effects of exposure to intense sound are quite variable, and so are the resulting recruitment curves The particular curve shown in Fig 7 was obtained by exposing one ear to a wide band of noise for 32 minutes at a sound pressure level of 130 db[2] Loudness balances were then made between the exposed and the normal ear at five frequencies between 1000 and 1700 c p s The points in Fig 7 represent the averages for the five frequencies We see that, although the threshold was raised by the noise exposure, the loudness heard by the exposed ear was essentially normal for tones at an SPL of about 110 db



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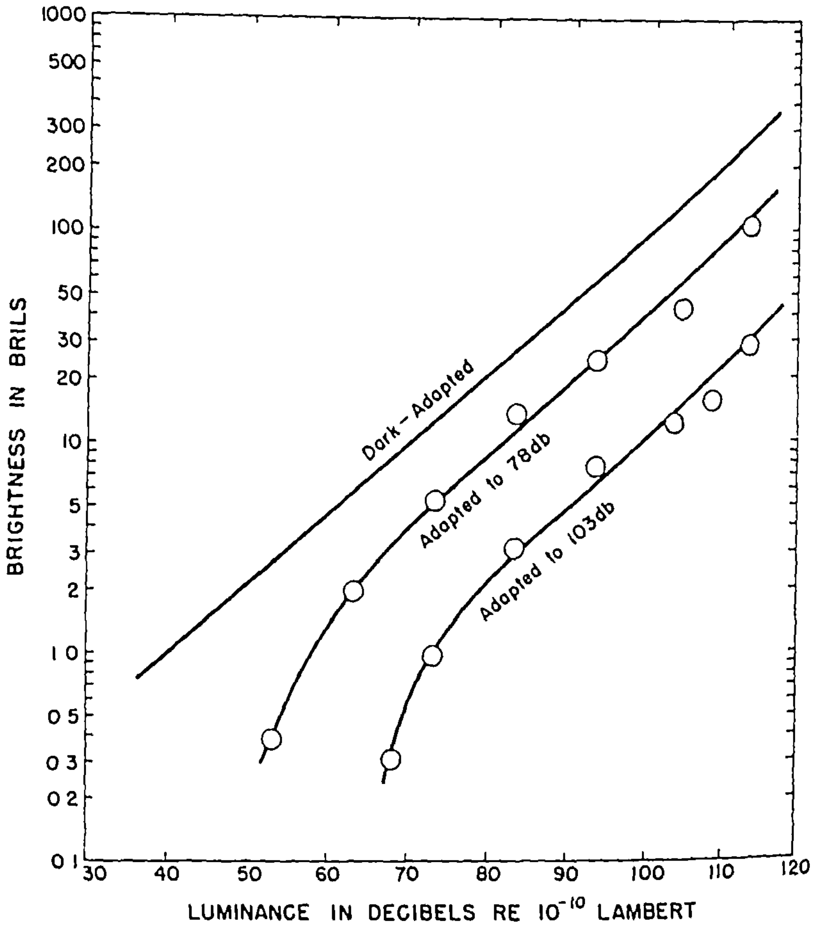

Fig. 8. Showing how light adaptation leads to brightness recruitment at low levels of luminance.

steep at the low end. On the other hand, there is an important difference to be noted. In the eye the recruitment is not complete. In other words, after our eyes are adapted to a bright light, all lights look dimmer than they would if we were dark adapted, but the effect on lights near threshold is relatively greater than the effect on the higher levels.

It should be mentioned that the positions of the curves through the points in Fig. 8 were determined in an experiment[1] involving brightness balances between the two eyes, with one eye dark adapted and the other light adapted. The points themselves were obtained by J C Stevens, who asked groups of 18 light-adapted observers to estimate the apparent brightness of various stimuli

4 Certain pathological conditions in the eye can also raise the absolute threshold without causing a correspondingly large change in the apparent brightness of intense lights I have recently had the opportunity of examining a case of what is called congenital stationary night-blindness The patient was a young man who apparently saw quite normally under high illumination (except for a slight myopia) but who saw nothing when the luminance was below about 40 db He has a brother and a sister who have similar deficiencies So far as I know, brightness perception in these cases has not been explored as thoroughly as loudness perception in ears that show auditory recruitment, but the fact that visual recruitment seems to exist in certain abnormal eyes is interesting evidence of a further functional similarity between the eye and the ear

In these remarks I have stressed some of the functional similarities between vision and audition It would be equally possible, of course, to stress the differences between these two remarkable sense organs, for there are indeed important differences Even where their behavior is similar, the underlying mechanisms may of course be quite different Not all the problems faced by audiology are similar to the problems that arise in the visual sciences, but there are enough parallels between the general laws of vision and those of hearing to make it highly profitable for us to study the eye in order to learn more about the ear and vice versa

Let us consider one final matter, concerning another type of loudness growth—a phenomenon that could be regarded as a form of recruitment, but one that seems to have no parallel in vision dependence of loudness on the band width of a sound From recent studies of this phenomenon there emerges the important concept of a critical band width

Figs 9 and 10 show examples of data from a study by Zwicker, Flottorp and Stevens[12] In these experiments the listener made a loudness balance between a comparison sound and either a complex of four pure tones (all at a constant

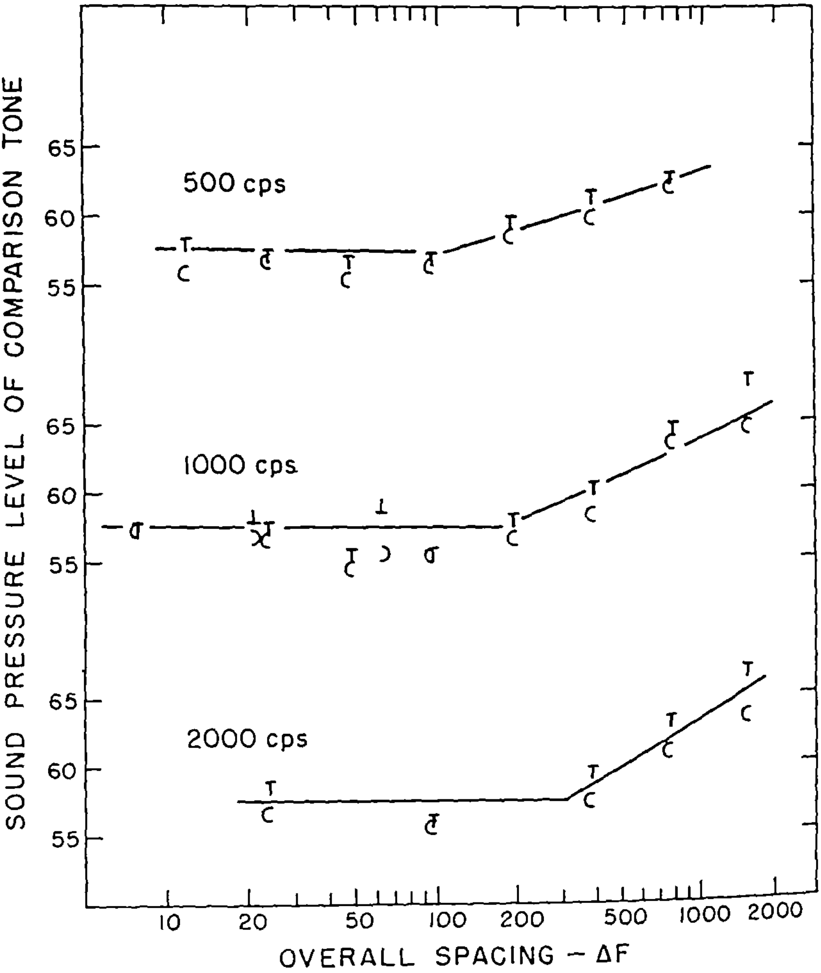

Fig 9 Showing how loudness depends on the overall spacing ΔF of a four-tone complex. The spacing of the tones was uniform about the center frequency indicated on each curve Each point is based on loudness balances by 16 to 22 listeners The symbol T means that the single comparison tone was adjusted C means that the complex was adjusted The lines through the data have a break at the frequencies determined by other critical-band determinations

level) or a band of noise In Fig 9 we see that, as the spacing between the tones is increased, the loudness of the complex remains essentially constant until the over all spacing ΔF reaches a critical value Beyond that point the loudness grows as the spacing is increased In other words, there is a kind of recruitment The critical value of ΔF depends on the frequency region in which the tones lie

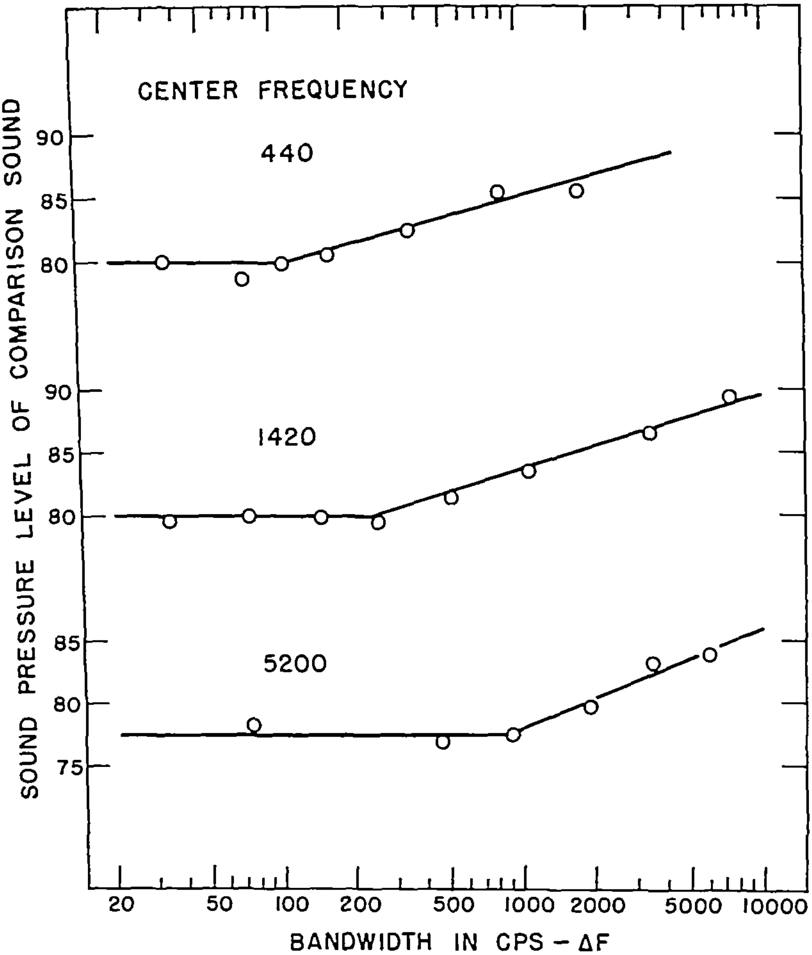

Fig 10 Showing how loudness depends on the band width ΔF of a noise of constant sound pressure level The lines through the data have a break at the frequencies determined by other critical-band determinations

In Fig 10 we observe a similar effect when we increase the width of a band of noise whose over all sound pressure level is held constant Beyond a critical point the loudness increases with band width, but as long as the energy lies within a critical band all that seems to matter for the determination of loudness is the sound pressure level of the noise In fitting the lines to the data in Figs 9 and 10 we placed the break between the horizontal and the rising segment at the points

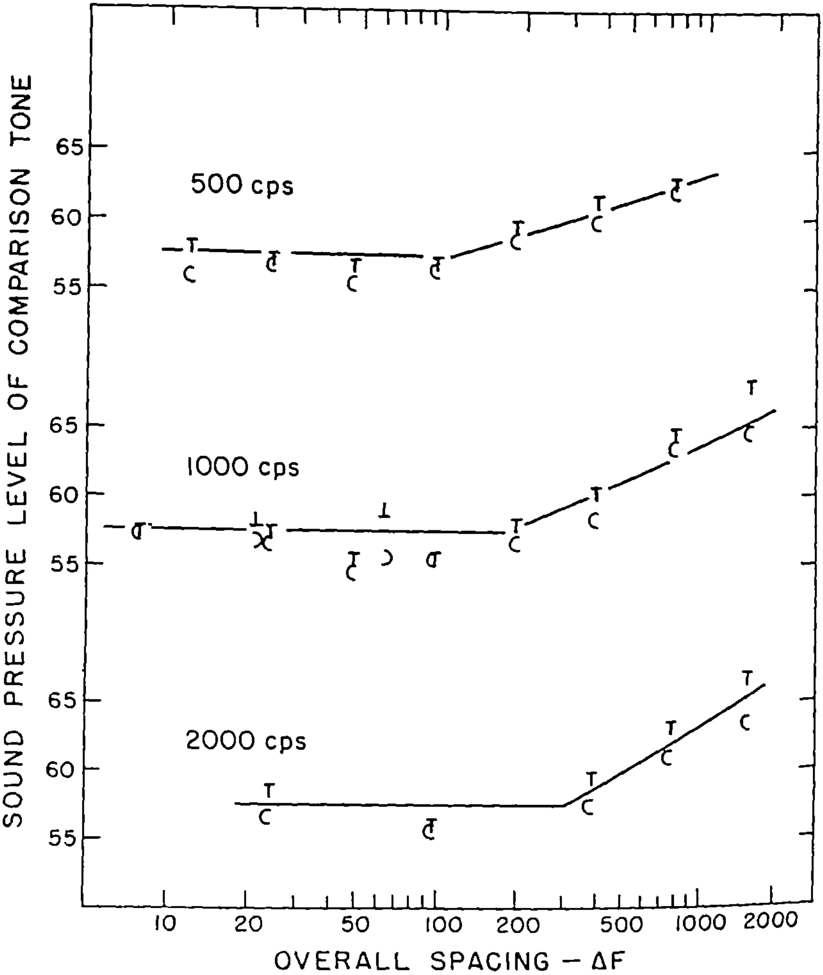

Fig 9 Showing how loudness depends on the overall spacing ΔF of a four-tone complex The spacing of the tones was uniform about the center frequency indicated on each curve Each point is based on loudness balances by 16 to 22 listeners The symbol T ' means that the single comparison tone was adjusted C means that the complex was adjusted The lines through the data have a break at the frequencies determined by other critical-band determinations

level) or a band of noise In Fig 9 we see that, as the spacing between the tones is increased, the loudness of the complex remains essentially constant until the over all spacing ΔF reaches a critical value Beyond that point the loudness grows as the spacing is increased In other words, there is a kind of recruitment The critical value of ΔF depends on the frequency region in which the tones lie

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# AN ATTEMPTED SYNTHESIS OF PSYCHO-ACOUSTIC TEST DATA IN THE AUDIOLOGICAL CLINIC

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More than a dozen separate tests, based upon as many different principles, have been proposed in recent years to assist in distinguishing "conductive" and "perceptive" deafness Many of these tests, even the classic Weber and Rinné examinations, do succeed well in making this first distinction, and some, such as careful BC audiometry, can often give a quite precise idea of the relative components in mixed deafness

One notes that the terms "conductive" and "perceptive," in past decades thought useful and clearcut, are today eroding rapidly A variety of causes and sites of "conductive" lesion render that term a catch-all with less precision than now required Mygind and others even speak of "conductive" lesions within the cochlea, here the original division has broken down completely On the other side, it is now clear that the category of "perceptive" deafness has even less explicit meaning It is relatively useless to lump all disorders of the auditory mechanism from perilymph to cerebrum under one compendium phrase, if one can be more specific

It is fair to say that one of the advances which has assisted otologists to be more specific has been the introduction into the clinic of a great deal of psycho-acoustic thought by the otologists and by supporting persons There is implicit here a whole new concept in otological diagnosis, namely, that since a particular physical disorder of pathology in certain dictated by measurements made in three other types of experiments. In other words, four different techniques have converged on the determination of this critical band width.

The critical band width thus measured turns out to be about 2.5 times as large as the critical band width originally proposed by Fletcher,[4] which was based on a different kind of experiment; nevertheless, in their dependence on frequency both Fletcher's band and this new band follow much the same course. The width of the new critical band is about 90 c.p.s. at the low frequency end of the spectrum. Near 1000 c.p.s. the widths is about 170 c.p.s., and near 10,000 c.p.s. it is about 2400 c.p.s.

Not only does this critical band width emerge in different kinds of experiments, but it also seems to be closely related to other important auditory functions. For example, each critical band occupies about the same width on the basilar membrane. Each band contains about the same number of just noticeable differences in pitch, and each contains roughly the same number of mels (units of subjective pitch). We have reason to believe, therefore, that this critical band width may come to hold an important place in auditory theory.

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Loudness-Increments Sensitivity
Sensitivity for Loudness by Constants
Pitch-Modulation Sensitivity
Pitch-Memory Sensitivity
Perstimulatory Adaptation
Post-Stimulatory Adaptation and Fatigue
Temporal Integration
Pure Tone Distortion Threshold
Masking of Speech and Pure Tones
Intelligibility of Speeded and Reverberant Speech

That this list is by no means complete is indicated by the fact that each of these tests has a bibliography of from several to dozens of items. In one recent review of recruitment, for example, over a dozen tests of recruitment and/or closely allied topics were listed. For another example, the field of loudness discrimination is burgeoning, and new tests not listed above are appearing all the time.

A number of these tests have been worked up for entirely non-clinical purposes, and their present audiological relevance has arisen mainly by chance—witness the work of Bekésy, Hood and others. Some writers have created audiological tests on the basis of some good guess as to the nature of the disorders and the capacities of the defective ear—Luscher, Langenbeck, Huizing, Hood again, Miskolczy-Fodor, and others. What happens is that someone suddenly has an idea that pitch discrimination, reverberant speech, or auditory masking, may assist in otological diagnosis, and a number of patients (it is the rule to use far too few for any solid reliability) are given the new test, with the result that the original author is quite enthusiastic about its nosological meaning.

Following this, another laboratory or clinic, changing experimental conditions freely, gives what is said to be the same test and finds conflicting or ambiguous results. This exact sequence has happened with tests of residual auditory fatigue, with masking, with intensity discrimination, with temporal integration, and with perstimulatory adaptation, to name several recent examples. At the present time, all workers are convinced that the principle is sound, that such patients can be shown to cause atypical behavior on a certain psycho-acoustic test, that test may be useful in throwing light on the diagnosis in another patient whose purely physical examination yields ambiguous concepts as to the locus or etiology of the dysfunction

Otologists have been impelled to seek for such inferential light in diagnosis of "perceptive" disorders because for the most part, these tissues in the auditory mechanism are, and must remain, inaccessible to the otoscope, and even to the exploratory surgery of the tympanum, in which such giant strides are currently being taken, however this may be in the future, it now seems possible with psycho-acoustic assistance to go beyond the rather coarse conductive-perceptive dichotomy and begin to break down the latter category into at least three subdivisions, neural, end-organ, and cochlear (non-end-organ) The neural category can of course be broken down further in some patients, and there is even the hope that in the future an attack can be made on the very indefinite category "cochlear (non-end-organ)"

Having thus placed psycho-acoustic thinking in perspective as a part of the armamentarium of the otologist, it remains to consider what test or tests could, or even should, be available in the complete clinic I should like to draw your attention to *1* a brief discussion of how some of the present psycho-acoustic tests have come to be suggested, *2* turn to one rational line of reasoning as to how a complete and mutually exclusive battery of such tests might be constructed, *3* how a "profile" of test results may correlate higher with diagnosis than results from any one or two tests

It will be instructive first to list a few of the psycho-acoustic tests or criteria which have been proposed for the clinic

AC-BC Audiogram, Level and Shape
AC-BC Differential
Threshold Uncertainty Interval
Shape of Speech Intelligibility Function
Loudness Balancing, and Shape of Recruitment Curve
Loudness-Modulation Sensitivity

Loudness-Increments Sensitivity
Sensitivity for Loudness by Constants
Pitch-Modulation Sensitivity
Pitch-Memory Sensitivity
Perstimulatory Adaptation
Post-Stimulatory Adaptation and Fatigue
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Following this, another laboratory or clinic, changing experimental conditions freely, gives what is said to be the same test and finds conflicting or ambiguous results This exact sequence has happened with tests of residual auditory fatigue, with masking, with intensity discrimination, with temporal integration, and with perstimulatory adaptation, to name several recent examples At the present time, all workers are convinced that the principle is sound, that such tests will ultimately prove valuable in diagnosis, but no general agreement is had on any specific test

The difficulty with these multi-various test possibilities is that they are not mutually exclusive, or in other terms, they are not factorially pure auditory traits A pure auditory trait is assumed to have a direct relation to the way the ear transduces and transforms the acoustic stimulus into cochleo-neural events A particular psycho-acoustic test, on the contrary, may be far from pure, partaking of so many primary auditory abilities that its results become ambiguous This means that a patient's atypically poor performance on this test cannot throw any light on the condition of specific tissues or processes in the auditory mechanism

As a result of studies at this laboratory* we now know, for example, that pitch discrimination, long thought to be a primary auditory ability, is actually broken down into two factors, pitch-memory and pitch-modulation A normal ear may be very good on one of these traits but only average on the other A defective ear on the same head may show a different pattern For another example, the detection of speech in noise is found *not* to be related to the detection of a sine wave, or bands of noise, or clicks, or Gaussian pulses, but is factorially complex with a large specific component of its own with alliance to factors of pitch and temporal patterns For a third example, we suspect speeded-up speech to be factorially fairly pure, by analogy, in the field of intelligence testing, to the primary mental ability of verbal facility

Only when a test is factorially pure can there be a chance of its representing fairly elementary operations of the auditory mechanism, so that if an ear performs badly on that test, the source of trouble in the auditory mechanism can be pinpointed A factorially complex test will almost hopelessly becloud the clinical issues We have already seen this happen for loudness discrimination, as I shall amplify later

I feel it is now possible to take a completely rational approach to the problem of audiological tests, using the technique of factor analysis as mentioned. Our work using this approach in pitch discrimination, loudness discrimination, contact detection, and speech reception has been summarized.* We can now suggest "tag tests" for two pitch factors, three loudness factors, and two or more distorted speech factors.

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*MRL Report No 57-4

As a paradigm, let us examine the matter of psycho-acoustic tests for susceptibility to acoustic trauma. Many industrial physicians and audiologists have proposed a brief exposure to moderate sounds, and a single threshold-shift index assigned to each man; but these proposed tests have used exposures ranging from 0.4 sec. to 10 min. frequencies over a broad range including white noise and clicks, and a wide variety of other dissimilarities exists. Should one give all these tests? The technique of factor analysis provides a means to reduce them to the fewest number which will sample the whole field of temporary threshold shift. Large groups of subjects would serve for the following program.

*a.* Outlining the area with a dozen or more specific test ideas. One would include among other things tests of aural overload, latent damage, short-duration adaptations, etc.

*b.* Tape-recording these preliminary tests with appropriate psycho-acoustic equipment and psycho-physical techniques acceptable by today's standards.

*c.* Trying them out for reliability, and standardizing them on pilot groups.

*d.* Tape-recording a final battery of tests and presenting to at least 200 subjects with normal ears.

*e.* Inter-correlating and factor analyzing.

*f.* Interpreting the data in terms of primary auditory abilities.

The smallest number of tests which would explain variance among subjects would then be cast into a predictive battery and administered to men destined for high noise areas

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*MRL Report No. 57-4.

Such an approach, with tapes widely distributed in several countries, would bring order into a confused field and bring final predictive success much closer to reality

Exactly the same sort of statistics-plus-psycho-acoustics is suggested for the otological clinic, except that the final winnowing of standardized pure tests in any area, such as loudness discrimination, would be further used to explore the diagnostic significance of each of the several primary abilities within the broad area of loudness discrimination

It may be well to explain this last point here Luscher and Zwislocki first succeeded in using a measure of loudness discrimination as a clinical index of recruitment, and subsequent data by Neuberger and others from that laboratory have convinced us that, in general, the otological conditions associated with recruitment are also associated with improved sensitivity for amplitude-modulation On the other hand one recalls Denes and Naunton's conclusion, exactly opposite from Luscher's, that near threshold the recruiting ear shows a relative improvement in loudness sensitivity Note, however, that Denes and Naunton used a "constants" method, with an interval of silence between two tones to be judged, it should now be clear why we feel that the techniques of loudness sensitivity by the "constants" method and the "amplitude-modulation" method *both* are applicable to the defective ear, and can both be used to assist in diagnosis Rather heavy criticisms of each method have been made by the other school, on the basis that "amplitude-modulation" produced side-bands to blur the "quality" of the tone or that the "constants" method yields an incongruously poor sensitivity at higher intensities, but it seems that such criticisms are beside the point, furthermore, it is not at all necessary to survey the several inconclusive reports and the several apparently contradictory reports, throw one's hands up and simply await the appearance of further inconclusive and inconsistent reports

The difference in results between the "constants" and the "modulation" tests goes far beyond the elementary notion that the exact value of a DL depends upon the techniques used to measure it—here we are not dealing with the same auditory trait In "amplitude-modulation" the ability is rendered more acute by whatever otological conditions cause recruitment, and this improvement exists at about equal strength over the whole range of sensation level On the other hand, in "constants" the ability is rendered more acute but *only in the region of rapid recruitment* A particular type of pathology may affect one trait in one way and the other in a quite different way

With this thought in mind we are better able to assess the several reports which have appeared since the original validating papers These reports are mutually informative, not contradictory

I have said perhaps enough to point out how we expect to generate newer and more meaningful ("purer") tests for auditory traits with continued effort Particularly, we feel that the areas of speech, of temporal patterning and rhythms, of masking and contact detection, of auditory fatigue and adaptation, and the area of inter-factor relationships must be explored

I now direct your attention to the third point, that in a particularly difficult diagnostic situation one may look at not only the results of tests one by one, but also at the interrelations among the sets of results It is the pattern, or profile, that may well be the really important clue For example, presbycusis is often characterized by lowered BC, a certain slope of audiogram, absence of recruitment, distortion of temporal integration, and lack of resistance to speeded speech If one looked at only one or two of these tests an uncertainty might exist, but the total picture becomes clearer when the test profile is considered For another example, we have published data showing that improved loudness discrimination need *not* be paid for with a deteriorated pitch discrimination, but that this is *always* true with acoustic trauma among subjects would then be cast into a predictive battery and administered to men destined for high noise areas

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# TRIPLET TESTING AND TRAINING—AN APPROACH TO BAND DISCRIMINATION AND ITS MONAURAL OR BINAURAL SUMMATION

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Recently the principle of what may be called qualitative speech audiometry has excited the interest of some investigators Kruisinga[1] studied the phenomena of phoneme confusion in cases of abrupt deafness, and he also investigated, in various types of hearing impairment, the change in intelligibility of the spoken voice as compared to that for the whispered voice

Guberina[2] examined the residual articulative function of impaired ears in discrete octave bands by using adequately chosen logatoms as test material

The great difference in change of the articulation curve for spoken voice as compared with that for whisper in different types of hearing impairment focused our attention to the significance of the test material in a qualitative sense This gave us the idea of measuring band articulation, while retaining intelligible speech as test material The great redundancy, which characterizes normal speech under favorable conditions makes it possible to use narrow band speech which is still intelligible

By means of suitable filters we are able to narrow the band width more and more until we approach the threshold of intelligibility for the normal ear To cover the whole tone scale by subsequent frequency bands, three different samples of speech are necessary, *i e* a low, a medium and a high quality of speech. Fig 1 shows the width of each of the three frequency bands equally weighted as to intelligibility for the Dutch language The filter characteristics are given in Fig 2

This split-up of the tone scale in three equivalent parts, with conserved intelligibility in each presents the possibility

We have a patient with advanced otosclerosis who exhibits a breakdown in "intensity-modulation" at weak levels, but whose loudness by "constants" remains quite good We have a patient with a pure conductive loss by BC, perstimulatory adaptation, and a half-dozen other signs, but who exhibits straight-line recruitment, disturbance of temporal integration, and diminished intensity-modulation We have a patient with a sudden unilateral loss above 500 c p s caused probably by a vascular spasm, with no AC-BC differential, extreme disturbance of temporal integration but with delayed and slight straight-line recruitment We have several patients with quick and complete recruitment, disturbance of temporal integration, no AC-BC differential, and history of acoustic trauma, but some do and some do not show unusual perstimulatory adaptation We have a patient with mixed deafness which would be considered purely conductive except that extremely distorted temporal integration reveals a minor cochlear lesion We have a patient with high tone cochlear deafness probably familial, with quick straight-line recruitment which indicates that cochlear lesions in addition to acoustic trauma and Menière's disease can distort temporal integration

It is no trouble to explore the protocols of patients in the literature from the practices of Palva, Bocca, Fournier, and also dozens of otologists in this country, who are accustomed to giving several psycho-acoustic tests where indicated or where possible, to find similar instances

Such of our data as seem internally self-contradictory we regard as among our potentially most powerful results They are at least not due to scanty sampling, since we are able to schedule both our civilian and our military patients for six to ten hours or more if needed We regard as in the pioneer stage only, the concepts of factorially pure auditory abilities and tests for them, and of the correlation between pathology in any tissue and a concomitant set of results on a multifactor test battery Our successes have been limited and have come slowly, but fortunately they have appeared at a rate just sufficient not to extinguish our conditioned drive bility is given by that part of the tone scale in which the threshold loss is smallest Depending upon the shape of the threshold audiogram the cerebral patterns of the patient may be low tuned, medium tuned or high tuned It appears that the shift in energy balance between the various frequency bands is closely related to the category of listeners to which the patient belongs

4 Triplet speech audiometry provides useful information

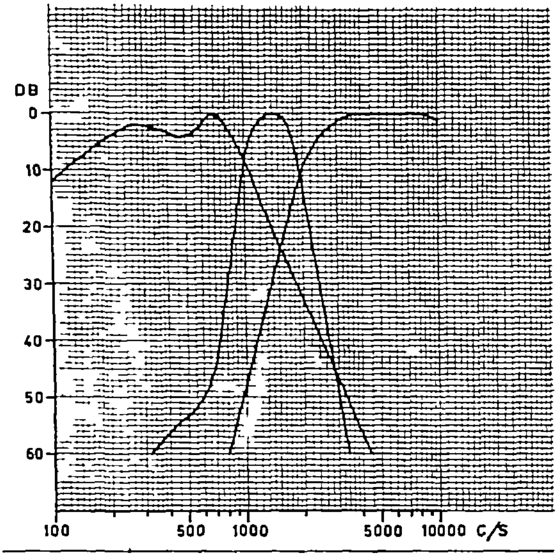

Fig 2 Filter characteristics used to realize a triple speech sample in equally weighted frequency bands (low medium and high)

regarding the fitting of a hearing aid on an analytic basis The analysis may tell us whether it is advisable to try to restore more or less the normal energy relations along the whole tone scale, or that preferably we should confine ourselves to a more or less selective amplification of that part of the tone scale in which the patient's discrimination skill has been kept up

5 In connection with band discrimination analysis we

of obtaining insight into a patient's partial discrimination ability We need only to determine his sentence intelligibility or his spondee articulation score at his most comfortable level

The application of this triplet audiometry on hard of hearing individuals leads to the following conclusions

*1* Triplet audiometry provides more information about the residual discrimination ability of a patient, especially as to its distribution along the tone scale

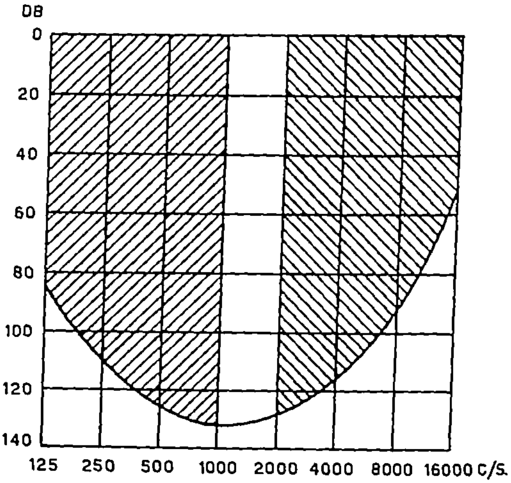

Fig 1 Triplet frequency bands equally weighted as to intelligibility for the Dutch language

*2* Depending upon the type and the duration of his hearing impairment, a patient's discrimination ability may be based upon a normal distribution of discriminative capacity along the whole tone scale, or it may be that his residual discriminative power is mainly concentrated in a rather narrow band of frequencies The latter may be the case despite the fact that his threshold audiogram still covers the whole tone scale

*3* In cases of long standing deafness with a non-uniform threshold loss in general, the main contribution to intelligi-

# EFFECTS OF AMBIENT NOISE ON SPEAKER INTELLIGIBILITY OF WORDS AND PHRASES *

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## I INTRODUCTION

Some years ago it was noticed that a speaker with normal hearing would unconsciously raise the level of his voice to compensate for the level of noise in which he was speaking This phenomenon was incorporated in the development of the "Lombard," or "voice-reflex" test, which was used to detect malingering in the testing of hearing It would be supposed that as the ambient level of noise for a speaker became greater there would be some changes in his intelligibility Hanley and Steer[2] found that untrained speakers, in the presence of noise, tended to reduce their rate of speaking, prolong syllables, and speak with greater intensity as the noise increased Subsequently, Pickett and Kryter[3] concluded that as a speaker increased his vocal intensity from normal level to a shout, his intelligibility decreased at the higher levels It is noted here, however, that their increases in vocal intensity were accomplished by raising the voice in quiet surroundings, technique that may result in speech with characteristics different from those produced by a speaker actually fighting noise It was not unreasonable to suppose that speech produced in noisy surroundings might actually incorporate some compensatory factors in it, and that within a certain limited range it might be more effective for a listener under poor reception conditions

If it could be shown that some of these changes actually

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*This study was done under Contract No AF 19(604)-1577 with Operational Applications Laboratory Bolling AFB Washington 25 D C (Report AFCRC TN 57-52 ASTIA Document No AD-110-068 ) direct attention to two-channel amplification To the credit of some data in the literature,[3] and also on account of our own recent experiments, it may be expected that in certain cases of hearing impairment the intelligibility may be markedly improved when the amplified speech is given through two separated selective bands in binaural stimulation For this purpose the distribution of discrimination skill along the tone scale must be known for each individual ear

A double channel system involves a greater flexibility in adjustment of the relative amplification of each frequency band, as well as to the choice of the band for each separate ear It says that a dual set of hearing aids may give a better opportunity of controlling "power" against "discrimination" It is rather this power discrimination relationship which is frequently disturbed due to non-uniform hearing loss, and often is hard to rectify by a single circuit

If in the near future we succeed in introducing the binaural aid, the triplet band data of each ear separately will give us useful information for obtaining an optimum improvement

*6* In young children with retarded speech development the triplet discrimination test lends itself principally to the detection of high tone or medium tone deafness (sloping or basin shaped audiograms)

*7* Finally this test may tell us whether it is advisable to start an auditory training program in connection with the use of a hearing aid, and if so, what kind of program should be preferable In this connection it should be emphasized that the triplet system lends itself to selective training in each of the three bands mentioned

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speaker's voice was provided by the headset, his monitoring being done only by internal sidetone

Stimulus materials consisted of five sets of spondee words and five air traffic control sentences at each of five recording levels for each of 15 speakers All words and sentences were different for each speaker at each level, that is, he never had the same material to read more than once during his entire recording stint The purpose of this was to prevent any accommodation to the phraseology itself Thus, each speaker read, in all, 25 spondees and 25 sentences His initial recording was made by wearing a dead headset, and his relatively low resultant voice level (65 db , C scale, one meter distant) served as the base level for the other four recording conditions He then recorded, in order, stimulus materials with 70, 80, 90, and 100 db of noise at the entrance to the ear canal To prevent accommodation to the masking level the noise was on in the headset only during actual production of the speech, the appearance of the noise serving as a cue for the speaker to record As soon as the test item was read, the noise was turned off for a given length of time to allow for listeners' written response Three seconds were allowed after each test spondee, eight seconds after each test sentence A push button operated by the experimenter controlled the noise in the speaker's headset

The order of the test material was rotated in such a manner that listeners for each of the recorded conditions heard all test words and sentences, since the final test tapes were arranged to present *1* all speakers' recordings in quiet, *2* all speakers' recordings in 70 db of noise, and so on, five tapes in all

After this collation of materials according to levels, all tapes were re-recorded through a General Electric BA-5A limiting circuit It is pointed out here that peak clip limiting was not employed The operation of this particular instrument is of broadcast quality, set for an attack of 100 microseconds and 0 6 second for 90 per cent recovery The purpose of such limiting was two-fold first, to remove the effects of increased vocal intensity from the experimental situation, act to increase intelligibility, we might anticipate a device that would exploit this fact For instance, a certain amount of masking might be introduced into the speaker's ears by means of a pre-calibrated device attached to his headset The listener, who would not be exposed to this noise, would, however, hear the improved output at his end of the link, and the importance of such a device would be obvious in air traffic control and other military voice communication applications

Inasmuch as automatic volume control is an integral part of modern transmission equipment, the accompanying increase in vocal intensity noted in the "voice reflex" reaction cannot properly be considered as one of the factors legitimate to test Consequently, the loudness (intensity) changes in the voice were compensated for in the construction of the test, a realistic structure in view of the eventual application of voice through a limited system

## II EXPERIMENTAL DETAILS

*A General Plan*—The Lombard reaction, while a general one, varies in magnitude as do other voice measures with individuals, therefore, the plan of the study was to get the reaction of several speakers under several levels of masking at the ear, comparing intelligibility of the speech so produced against a constant background of masking noise with a large number of listeners To avoid attempts on the speakers' parts to control their vocal level, none were informed of the voice reflex phenomenon

*B Speakers and Stimulus Materials*—Fifteen university students, three male and twelve female, served as speakers All were of general American dialect and inexperienced with voice recording methods

Recordings were made with an Altec 21-C condenser microphone positioned along the speaker's cheek with the button behind the corner of the mouth, out of the breath stream During recording each speaker wore a pair of PDR-8 headphones These headphones fed the taped output of a Grason-Stadler White Noise Generator (Model 455-B) from an Eko-tape recorder to the ears of the speaker No feedback of the speaker, and the playback level measured 70 db (C scale) at a point ten feet in front and on the axis of the loud-speaker Each listening session lasted 30 minutes, with each group of 40 evaluating the speech produced under one of the five masking conditions

*E Analysis of Data*—Intelligibility scores were computed for words and sentences The latter were scored by percentage of key words correct, the former on percentage correctly identified Physical measurements of intensity and duration of the original, noise-free speech signals were made and treated with analysis of variance for differences Experimental data were also arrayed in graphic form to show trends

## III RESULTS AND DISCUSSION

*A Intelligibility*—Fig 2 shows the intelligibility of both words and sentences as heard in a given constant S/N ratio To determine the extent of possible score, one of the test tapes was presented to a group of 40 listeners without any noise masking A score of more than 98 per cent on both words and sentences was achieved, indicating almost perfect reception under excellent reception conditions Data for listening sessions with speech produced in quiet, 70, 80, and 100 db of speaker-masking appear in Fig 2, scores for the 90 db recording level being unfortunately not available, due to an administrative error in giving the tests The regular behavior of the adjoining conditions would indicate, however, that similar results would have been obtained

Of immediate interest is the difference in intelligibility scores between the quiet-produced and noise-produced speech It may be seen that the first level of noise in the speaker's ears (70 db ) resulted in speech 35 per cent more intelligible in respect to words, 27 per cent more intelligible in respect to sentences From that level on, no statistical changes in scores are noted It is apparent, therefore, that throughout the range tested, no advantage was gained by the speakers from the heavier masking levels used during recording The curves also indicate that during the steady-score region of 70 to 100 second, because such type of intensity reduction is also employed in aircraft broadcast circuits The total range of limiting involved in these tapes amounted to approximately 10 db

After re-recording, an overlay of wideband random noise was recorded on the test tapes The noise overlay was recorded at a level of 4 db lower than the peak values of the speech signals, both speech and noise being read on the same VU meter As a check, the completed tapes, speech signals plus noise overlay, were run through a graphic level recorder, Sound Apparatus Co, Model HPL The resultant tracings verified the speech peaks as being 4 db above the noise level Fig 1 shows this setup schematically

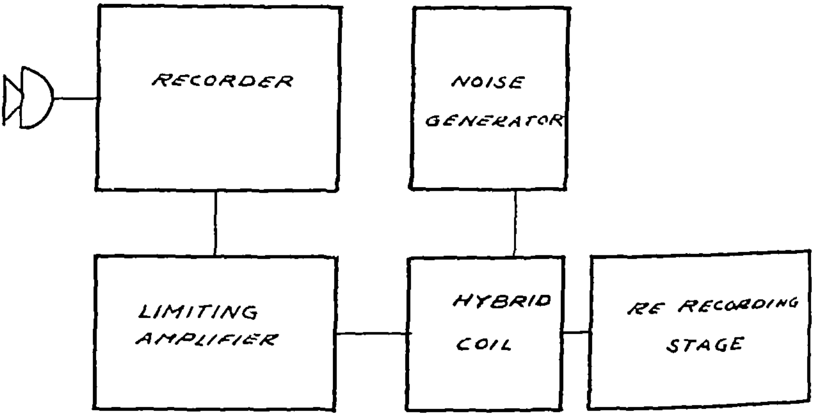

Fig 1 Schematic Diagram of Stimulus Preparation

*C Listeners*—Listeners were 204 AFROTC cadets at The Ohio State University They were divided into five groups of about 40 persons each

*D Test Administration*—All listening groups were instructed in the same manner on the mechanics of filling out the test blanks Stimuli were then administered with an Ampex 600 tape recorder and an Ampex 620 speaker-amplifier system to listeners seated in an average-size classroom The nearest listeners were approximately six feet from the loud-

TABLE I

LEVEL OF SPEECH OUTPUT UNDER CONDITIONS OF BROADBAND RANDOM NOISE MASKING AT THE SPEAKER'S EARS

| Condition | Words (db.) | Diff. (db.) | Sentences (db.) | Diff. (db.) |
|---|---|---|---|---|
| Quiet | 65.0 | | 68.8 | -- |
| 70 db | 70.8 | 5.8 | 71.9 | 3.1 |
| 80 db | 71.9 | 1.1 | 72.8 | 0.9 |
| 90 db | 72.8 | 0.9 | 73.9 | 1.1 |
| 100 db | 74.1 | 1.3 | 74.9 | 1.0 |

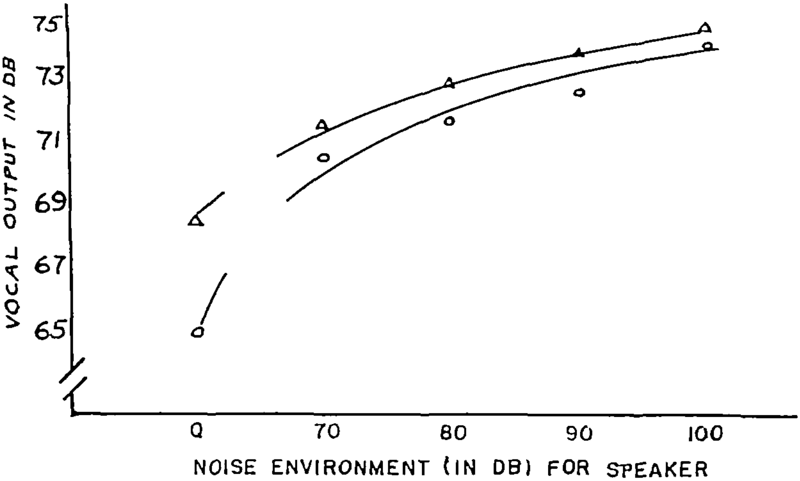

Fig. 3. Increase in vocal output with increase of masking level at the speaker's ears.

0.38 db/db. From his description of procedure it is possible that this higher figure might reflect some measurement of breath blast caused by microphone placement in his experiment. The trend of the tabled values is shown in Fig. 3. An interesting point here is that in all conditions the level for spondee was less than for sentences, both readings being taken on maximum peaks of the utterances.

*2. Duration Changes*—The same recording traces measured above for intensity changes yielded the comparative duration measurements tabled below.

As in the case of intensity, increased masking level resulted in a steady increase in duration, with the greatest difference db the context offered by the sentence settings resulted in about 10 per cent more intelligibility From these results we would assume that a real and sizeable increase in the intelligibility of speech is realized by introducing some degree of noise into a speaker's ears It may be possible that the same amount of increase might be effected with less masking noise, and it is also possible that masking levels higher than 100 db might produce different results

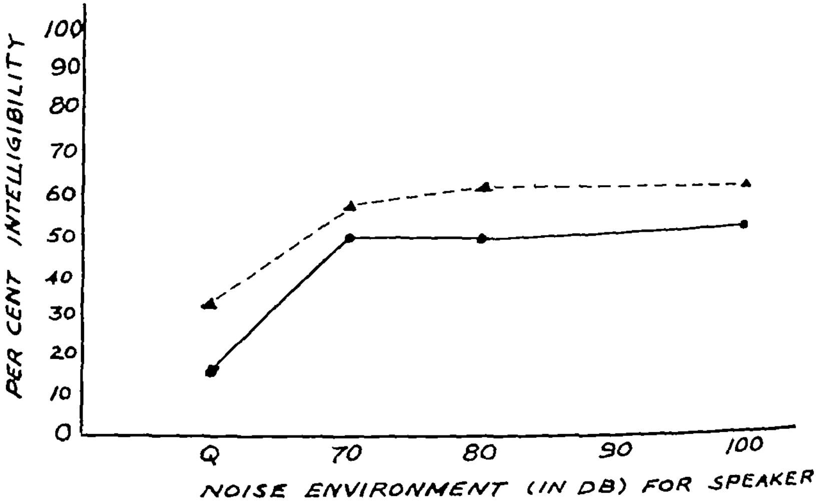

Fig 2 Intelligibility of words and sentences spoken in various levels of noise and heard at a constant S/N ratio of zero db

*B Physical Measures—1 Intensity Changes*—Although intensity of the voice did not contribute to the intelligibility results, the original recordings could be measured to estimate the effect of speaker-masking on his production levels The initial stimulus tapes were measured on the graphic level recorder to determine both duration and intensity Results re 0002 dyne/cm$^2$ are shown in Table I

The largest intensity increase comes, both for words and sentences, when the first level of masking is employed After that, succeeding increments of 10 db masking produced an average vocal increase of approximately 1 db This estimate of 0 1 db/db differs from a previous estimate by Korn[3] of

TABLE I

LEVEL OF SPEECH OUTPUT UNDER CONDITIONS OF BROADBAND RANDOM NOISE MASKING AT THE SPEAKER'S EARS

| Condition | Words (db ) | Diff (db ) | Sentences (db ) | Diff (db ) |
|---|---|---|---|---|
| Quiet | 65 0 | — | 68 8 | — |
| 70 db | 70 8 | 5 8 | 71 9 | 3 1 |
| 80 db | 71 9 | 1 1 | 72 8 | 0 9 |
| 90 db | 72 8 | 0 9 | 73 9 | 1 1 |
| 100 db | 74 1 | 1 3 | 74 9 | 1 0 |

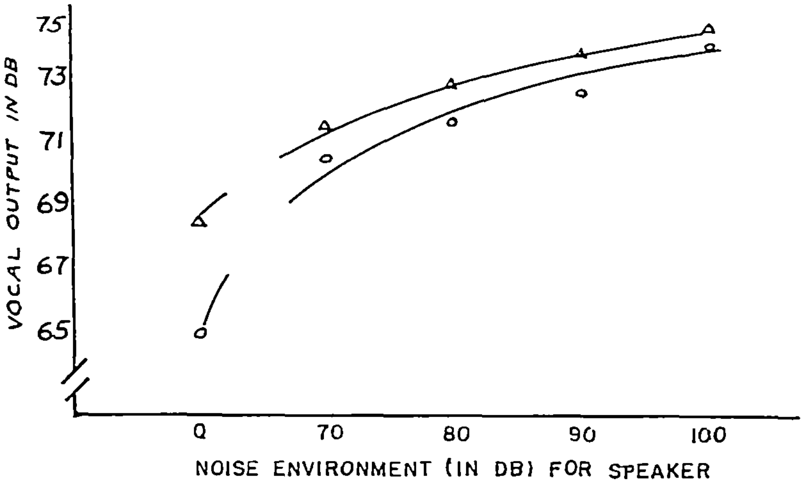

Fig 3 Increase in vocal output with increase of masking level at the speaker s ears.

0 38 db /db From his description of procedure it is possible that this higher figure might reflect some measurement of breath blast caused by microphone placement in his experiment The trend of the tabled values is shown in Fig 3 An interesting point here is that in all conditions the level for spondee was less than for sentences, both readings being taken on maximum peaks of the utterances

2 *Duration Changes*—The same recording traces measured above for intensity changes yielded the comparative duration measurements tabled below

As in the case of intensity, increased masking level resulted in a steady increase in duration, with the greatest difference

TABLE II

DURATION (IN CENTISECONDS) OF WORDS AND PHRASES PRODUCED UNDER CONDITIONS OF BROADBAND RANDOM NOISE MASKING

| Conditions | Words | Diff. | Sentences | Diff. |
|---|---|---|---|---|
| Quiet | 67.0 | — | 170.0 | — |
| 70 db | 77.0 | 10.0 | 197.0 | 27.0 |
| 80 db | 84.0 | 7.0 | 202.0 | 3.0 |
| 90 db | 86.0 | 2.0 | 210.0 | 8.0 |
| 100 db | 88.0 | 2.0 | 213.0 | 3.0 |

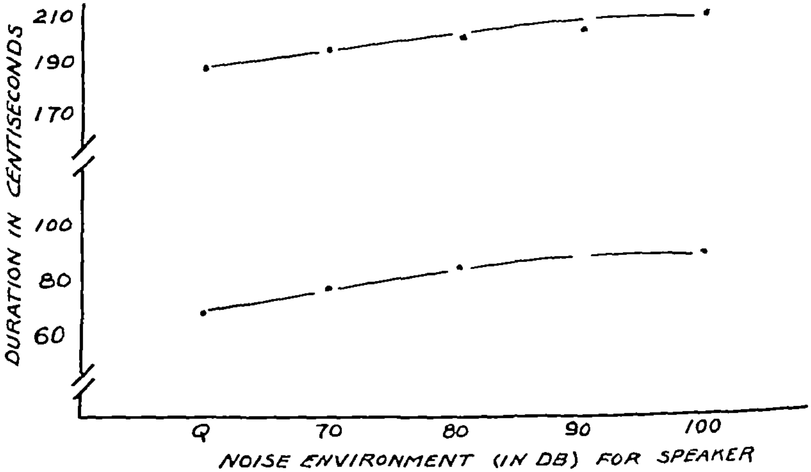

Fig. 4. Increase in duration of words and sentences with increase of masking in speaker's ears.

coming with the first onset of the masking noise. Duration functions for the two types of test material are shown in Fig. 4.

Since the intensity factor had been controlled, it cannot be held accountable for the observed increase in intelligibility score associated with noise-produced speech, and in view of the fact that duration changes from one condition to the next were so small as to be statistically insignificant, we should most logically look to other dimensions of the voice for the reasons. The answer may lie in the area of less well defined measures, such as quality and stress, or in the relationships between the sequences of the phonemes making up the speech signal. Suffice it to say, however, that the magnitude of intelligibility change between the first and second experimental conditions might make it well worthwhile to attempt further exploration and application of it The notion of a device for military communication would seem to be feasible for immediate development after additional tests on the range of speaker masking between quiet and 70 db to discover minimum masking level Further studies should also be made on the extent of speaker accommodation to the masking influence The stable and statistically nonsignificant intelligibility scores obtaining in test materials produced under noise conditions of this study may also offer a tool to the audiologist who employs live voice presentation of tests

## IV CONCLUSIONS

From the evidence presented above it is concluded that

*1* There is a measurable and important increase in the intelligibility of both words and sentences produced by speakers operating with a broadband random noise mask in their headsets

*2* The intelligibility values of speech produced under 70 db of masking were statistically equivalent to those produced under 80 and 100 db of masking

*3* Plots of both mean duration of speech elements and vocal output show a regular increase with increase in speaker masking

*4* The range of masking between "Quiet," (estimated by curvilinear extrapolation to be approximately 54 db ) and 70 db of masking needs further exploration to determine additional points on both the intelligibility and vocal output curves, and it is suggested that live voice tests for hearing evaluation consider the use of sufficient speaker masking to effect the vocal stability observed in this study

*5* It is recommended that the observation of increased intelligibility be put to operational test in aircraft circuits

*6* It is recommended that the aforementioned operational test, if successful, should result in the engineering of a device for emergency use in air-ground communications for speakers in relatively quiet speaking environments

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# A COMPARISON OF PICTURE RESPONSE AND HAND RAISING TECHNIQUES FOR PURE TONE AUDIOMETRY WITH YOUNG CHILDREN

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In order to teach the child with a hearing loss to utilize his hearing to his best advantage, an early educational program is necessary This requires early detection of reduced acuity, and it becomes desirable that hearing testing techniques be developed for use with the young child

Among the methods in current use for testing young children are noise makers, speech reception, subjective pure tone audiometry, and PGSR Pure tone audiometrics are preferable to measurement with noise making apparatus and speech for at least part of the testing protocol, because the audiometer gives information about acuity at specific frequencies, and intensity levels are calibrated In some quarters the PGSR test for children is not considered desirable (Although pure tones are used, validity and reliability of testing are questioned because of subjectivity in interpreting results and difficulties in conditioning In addition, PGSR sometimes is considered to be unpleasant for the child and detrimental for follow-up testing and training) For these reasons subjective pure tone audiometry continues to be the method most generally preferred for testing the hearing acuity of children, however, many children will not respond to pure tone audiometry when the standard response is used (*i e*, when the child is expected to raise his hand when he hears the tone) The test procedure must be altered so that suitable responses can be obtained Pure tone test procedures for children should satisfy at least the following criteria[1, 2]

*1* Simple association between pure tone stimulus and response
*2* Motivate the child
*3* Take into account child's short attention span
*4* Require only a gross motor response
*5* Not require a verbal response
*6* Aid the examiner to gain rapport
*7* Produce valid and reliable results
*8* Preferably require only one examiner
*9* Allow monaural measurements
*10* Be economical
*11* Require only simple manipulation of apparatus

Although the standard pure tone audiometry method satisfies some of these criteria, in several important aspects it may be improved upon

Attempts to devise pure tone audiometric procedures for children have centered mostly around techniques for motivating the children to listen attentively and to respond appropriately To accomplish these goals a number of varieties of the peep-show technique have been devised[3, 4, 5] In all cases, the basic situation is that the child is rewarded for making a correct response when the tone is on, and he is not rewarded if he responds when the tone is not on Other techniques for pure tone testing with children have been to associate objects with the audiometric tones, and to carry on pre-testing training programs to associate sound with a response[6-8, 9]

Although the literature on methods for testing the hearing of young children is growing, little has been done to compare the results of acuity measurements made using various subjective techniques It was the purpose of this study to compare the standard technique (hand raising) with a picture response technique (modified peep-show) for pure tone hearing testing of pre-school children The two response techniques were compared with respect to eight criteria, presumed to be important for evaluating a hearing test, mentioned below

## PROCEDURE

Thirty-nine normal hearing children were used for the study They were pupils at the nursery school of The Pennsylvania State University, and all were children of faculty members of the university, or of business men of the town Their chronological ages ranged from three years three months to five years two months Their mental ages, according to a Stanford-Binet test, ranged from three years five months to six years nine months The average I Q of the children was 121 There were 19 males and 20 females (Although as a group the children were of superior mental ability, this factor would not be expected to be critical to interpretation of the experimental results Each child acted as his own control when comparing the two test methods )

A modified peep-show apparatus was used for part of the experimental testing Switching circuits were arranged, so that if a child heard a tone in his earphone (monaural) and pressed the top of a box on the table in front of him, the lights in the room went off and he saw an attractive colored picture of an animal projected on a screen If he pressed the box top when there was no tone, there was no such reward A standard pure-tone audiometer was used The animal pictures were on 2x2 inch slides, and projected by a semi-automatic slide projector If the child became disinterested in a picture the examiner pressed a button attached to the projector, and a new picture became available Testing was done in a quiet room near the nursery school The same room and audiometer were used for the standard procedure, but the child was expected to raise his hand when he heard the tone Children were alternated during the testing program, so that half of them had their left ears tested first and half had their right ears tested first, half were tested with the picture response technique first and half were tested by the standard hand raising technique first It was attempted to give each child both tests in both ears for frequencies 1000, 2000, and 500 c p s, in the order mentioned Approximately two weeks after the initial testing each child was given the complete battery test again

The two test procedures were compared on the basis of the following eight criteria

*1* Three frequency average threshold
*2* Test reliability
*3* Time required to orientate child to the test
*4* Ease of orientation
*5* Number of false responses
*6* Three frequency threshold test time
*7* Per cent of three frequency tests completed
*8* Child's preference

Not all children could be given the complete battery test Some cooperated during one of the tests but refused the other, or occasionally only a partial test could be obtained on an ear, therefore, in the following analyses the number of cases considered does not always reach 39, and often the number is different for the various considerations

## RESULTS

*Three frequency average threshold*—The average threshold for the three frequencies on a single ear of a child was computed and used as the threshold value Table I shows the means of these threshold values for the two test methods for left ears, and for right ears on the initial test, and on the retest The mean thresholds were compared, using the t test for related samples Only children on whom complete tests could be obtained were included It can be seen that in all comparisons the picture response technique gave more acute mean thresholds than did the standard response method

Only for the right ear on the retest did the difference between means fail to reach the .10 level of statistical significance. It also will be noticed that the retest thresholds are more acute than the initial test thresholds. Picture response thresholds averaged about 3 db more acute than than response thresholds on the initial test.

*Test Reliability.*—To measure test reliability the test-retest threshold value 0, 0-5, and more than 5 db from the initial percentages of all ears (both left and right) deviating in threshold value 0, 0-5, and more than 5 db from the initial test on the retest were computed for each frequency, and are shown in Table II. Approximately one-third of the ears had 0 db deviation for each method, and approximately three-fourths of the ears had deviations of 5 db or less from test on retest for each method. Despite the observed per cent differences between methods for individual frequencies, the differences appear to balance out, and in general both methods

TABLE I

MEAN DB THRESHOLDS AND t TESTS

| | Picture | Standard | N | t | $\sigma_{MD}$ | P |
|---|---|---|---|---|---|---|
| A.D. test | 9.0 | 12.1 | 19 | 2.79 | 1.10 | .02 |
| A.S. test | 8.6 | 11.3 | 20 | 1.98 | 1.14 | .10 |
| A.D. retest | 6.8 | 7.4 | 20 | .38 | 1.41 | .70 |
| A.S. retest | 5.6 | 8.8 | 20 | 1.94 | 1.10 | .10 |

TABLE II

PER CENT OF EARS SHOWING DB VARIATIONS IN THRESHOLD BETWEEN TEST AND RETEST

| | PICTURE | | | |
|---|---|---|---|---|
| c.p.s. | N | 0 db | 0-5 db | <5 db |
| 500 | 52 | 35 | 79 | 21 |
| 1000 | 53 | 26 | 77 | 23 |
| 2000 | 53 | 43 | 81 | 19 |
| Mean % | — | 35 | 79 | 21 |
| | STANDARD | | | |
| c.p.s. | N | 0 db | 0-5 db | <5 db |
| 500 | 36 | 33 | 69 | 31 |
| 1000 | 36 | 50 | 78 | 22 |
| 2000 | 36 | 33 | 75 | 25 |
| Mean % | — | 39 | 74 | 26 |

appear to have similar reliabilities. (Although it is not shown in Table II, inspection of the original data indicated that in most cases the retest thresholds were more acute than the initial test thresholds. This trend was seen in Table I.)

*Orientation Time*—When a child entered the testing room he was made to feel comfortable and induced to sit at the table holding his switching box. After the tester demonstrated wearing the earphones it was possible to put the phone on the child, usually without difficulty. The timing of the orientation began when the earphones were on the child, and ended when the child gave three correct responses to the presence of a 1000 c.p.s. tone presented at 50 db hearing loss. Verbal instructions and demonstrations were used to teach the child the test. The mean time required to orientate the children who were given the standard response test first was compared with the mean time required to orientate the children who were given the picture response test first. (It will be recalled that in the subject group half were presented the picture response test first, and half were presented the standard response test first.) The numbers of children in the two groups for this comparison were not the same because some children could not be orientated to one or the other tests. For the 18 children orientated to the picture response test first, the mean time required for orientation was 87 seconds; the 15 children who could be given the standard response test first had a mean orientation time of 155 seconds. A t test computed between these two means gave a value of 1.80, significant between the .05 and .10 levels.

*Ease of Orientation*—A judgment was made by the examiner as to the ease of orientating each child to the first test he was given. The basis for this judgment was partly on the amount of time it took to orientate the child, but largely on the degree to which his interest could be aroused and held during the orientation, and general impression of his quickness to gain insight into the task required. Of the children given the standard response test first, 70 per cent (14 children) were easy to orientate, 15 per cent (three children) were difficult to orientate, and 15 per cent (three children) were impossible to orientate. For children given the picture

test first 79 per cent (15 children) were easy to orientate), 5 per cent (one child) was difficult to orientate, and 16 per cent (three children) were impossible to orientate Although there was a slightly greater proportion of children easy to orientate to the picture test procedure, the difference between this proportion and the proportion easy to orientate with the standard response technique was not statistically significant according to a t test (t 50, P 60)

In general, those children who were easy to orientate by one technique were easy to orientate by the other technique when it was given second in the testing sequence Where differences existed, they always were in favor of the picture test method For example, some children given the picture test first and easy to orientate were difficult or impossible to orientate to the standard response test when it followed

TABLE III

MEAN TEST TIME IN SECONDS FOR A THREE FREQUENCY TEST

| | Picture | Standard | N | $\sigma_{MD}$ | t | P |
|---|---|---|---|---|---|---|
| A.D | 246 | 230 | 14 | 24 42 | 68 | 60 |
| A S | 310 | 261 | 20 | 19 56 | 2 48 | 05 |

*Consistency of Response*—Consistency of response was measured by noting how many times each child made responses when there was no tone present for each of the tests The mean number of false responses made during the standard test was two, during the picture test the mean was 1 75 A t test between these mean values was not significant (t 16, P 90)

*Three Frequency Threshold Test Time*—Timing of the threshold testing began after completion of the orientation, *i e*, after the child had made three successive correct responses Because some children could not be tested in both ears for one or both of the test procedures, test times for right and left ears were separated, and in the analysis only ears which could be tested by both methods were considered to make possible a match groups t test Table III shows the test times and t test results It can be seen that the

standard response method required less time than the picture response method, but the difference was significant for only the left ears. (It was the examiner's impression that the picture response test required longer time because the children enjoyed seeing the pictures so much.)

*Per Cent Complete Tests Obtained*—Not all children could be tested completely (three frequencies in both ears) with both response methods. Some could be tested in one ear only by a given method, and others could not be tested at all. Table IV shows the per cent of the 39 children who could not be tested in either ear, who could be tested in one ear only, and who could be tested in both ears by each of the methods. Each child was tabulated for his testing with the picture test and for his testing with the standard test. Thirty-eight per cent (15 children) could be tested completely by both methods, 10 per cent (four children) could be tested in one ear only by both methods, and 18 per cent (seven children) could not be tested by either method, however, it will be noticed that 21 per cent (eight children) could be tested in both ears with the pictures, but not at all with the standard response method, and that 10 per cent (four children) could be tested in both ears, using the pictures, but in only one ear by the standard method. Thus a total of 69 per cent (27 children) could be tested in both ears by the picture method, but only 38 per cent (15 children) could be tested in both ears by the standard response method. (In this analysis if a child could be tested for only one or two frequencies in an ear, the result was not counted as a test for that ear.)

TABLE IV

PER CENT OF THREE FREQUENCY TESTS OBTAINED
(39 Children)

| STANDARD | PICTURE<br>No Test | One Ear | Two Ears |
|---|---|---|---|
| No Test | 18 | 2 | 21 |
| One Ear | 0 | 10 | 10 |
| Two Ears | 0 | 0 | 38 |

*Child's Preference*—At the end of an initial testing session

test first 79 per cent (15 children) were easy to orientate), 5 per cent (one child) was difficult to orientate, and 16 per cent (three children) were impossible to orientate Although there was a slightly greater proportion of children easy to orientate to the picture test procedure, the difference between this proportion and the proportion easy to orientate with the standard response technique was not statistically significant according to a t test (t 50, P 60)

In general, those children who were easy to orientate by one technique were easy to orientate by the other technique when it was given second in the testing sequence Where differences existed, they always were in favor of the picture test method For example, some children given the picture test first and easy to orientate were difficult or impossible to orientate to the standard response test when it followed

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standard response method required less time than the picture response method, but the difference was significant for only the left ears (It was the examiner's impression that the picture response test required longer time because the children enjoyed seeing the pictures so much.)

*Per Cent Complete Tests Obtained*—Not all children could be tested completely (three frequencies in both ears) with both response methods Some could be tested in one ear only by a given method, and others could not be tested at all Table IV shows the per cent of the 39 children who could not be tested in either ear, who could be tested in one ear only, and who could be tested in both ears by each of the methods Each child was tabulated for his testing with the picture test and for his testing with the standard test Thirty-eight per cent (15 children) could be tested completely by both methods, 10 per cent (four children) could be tested in one ear only by both methods, and 18 per cent (seven children) could not be tested by either method, however, it will be noticed that 21 per cent (eight children) could be tested in both ears with the pictures, but not at all with the standard response method, and that 10 per cent (four children) could be tested in both ears, using the pictures, but in only one ear by the standard method Thus a total of 69 per cent (27 children) could be tested in both ears by the picture method, but only 38 per cent (15 children) could be tested in both ears by the standard response method (In this analysis if a child could be tested for only one or two frequencies in an ear, the result was not counted as a test for that ear )

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| One Ear | 0 | 10 | 10 |
| Two Ears | 0 | 0 | 38 |

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*Per Cent Complete Tests Obtained*—Not all children could be tested completely (three frequencies in both ears) with both response methods Some could be tested in one ear only by a given method, and others could not be tested at all Table IV shows the per cent of the 39 children who could not be tested in either ear, who could be tested in one ear only, and who could be tested in both ears by each of the methods Each child was tabulated for his testing with the picture test and for his testing with the standard test Thirty-eight per cent (15 children) could be tested completely by both methods, 10 per cent (four children) could be tested in one ear only by both methods, and 18 per cent (seven children) could not be tested by either method, however, it will be noticed that 21 per cent (eight children) could be tested in both ears with the pictures, but not at all with the standard response method, and that 10 per cent (four children) could be tested in both ears, using the pictures, but in only one ear by the standard method Thus a total of 69 per cent (27 children) could be tested in both ears by the picture method, but only 38 per cent (15 children) could be tested in both ears by the standard response method (*In this analysis if* a child could be tested for only one or two frequencies in an ear, the result was not counted as a test for that ear )

TABLE IV

PER CENT OF THREE FREQUENCY TESTS OBTAINED
(39 Children)

| | | PICTURE No Test | One Ear | Two Ears |
|---|---|---|---|---|
| STANDARD | No Test | 18 | 2 | 21 |
| | One Ear | 0 | 10 | 10 |
| | Two Ears | 0 | 0 | 38 |

*Child's Preference*—At the end of an initial testing session

test first 79 per cent (15 children) were easy to orientate), 5 per cent (one child) was difficult to orientate, and 16 per cent (three children) were impossible to orientate Although there was a slightly greater proportion of children easy to orientate to the picture test procedure, the difference between this proportion and the proportion easy to orientate with the standard response technique was not statistically significant according to a t test (t 50, P 60)

In general, those children who were easy to orientate by one technique were easy to orientate by the other technique when it was given second in the testing sequence Where differences existed, they always were in favor of the picture test method For example, some children given the picture test first and easy to orientate were difficult or impossible to orientate to the standard response test when it followed

TABLE III

MEAN TEST TIME IN SECONDS FOR A THREE FREQUENCY TEST

| | Picture | Standard | N | $\sigma_{MD}$ | t | P |
|---|---|---|---|---|---|---|
| A D ........ ...... | 246 | 230 | 14 | 24 42 | 68 | 60 |
| A S ........ .... | 310 | 261 | 20 | 19 56 | 2 48 | 05 |

*Consistency of Response*—Consistency of response was measured by noting how many times each child made responses when there was no tone present for each of the tests The mean number of false responses made during the standard test was two, during the picture test the mean was 1 75 A t test between these mean values was not significant (t 16, P 90)

*Three Frequency Threshold Test Time*—Timing of the threshold testing began after completion of the orientation, *i e*, after the child had made three successive correct responses Because some children could not be tested in both ears for one or both of the test procedures, test times for right and left ears were separated, and in the analysis only ears which could be tested by both methods were considered to make possible a match groups t test Table III shows the test times and t test results It can be seen that the

with respect to ease with which children can be orientated to give correct responses

*5* There is no significant difference in the number of false responses given during administration of the two tests

*6* The picture testing procedure takes longer for the obtaining of thresholds at three frequencies In the present study the difference was statistically significant for only the left ears of the subjects, for these ears the mean difference was about 50 seconds

*7* With respect to the success with which a test at at least three frequencies can be done, the picture response method has a clear advantage over the standard response method

*8* Children prefer the picture response test method

When considering these eight criteria for comparing the two test techniques, the standard response method is supported only by the criterion of test time The criteria of reliability and number of false responses demonstrated no support for either method over the other The picture response method was supported by the other five criteria

It is questionable whether the issue of which test is superior should be decided by the number of criteria in favor of each, rather, the relative importance of the various criteria should be considered Although the standard response method took less time to administer after orientation, the difference was more than cancelled by the shorter orientation time for the picture method The picture method produced slightly more acute thresholds than did the standard response method, but this difference is of little numerical or theoretical importance Because any threshold is determined by definition, *i e*, hearing acuity is judged in terms of whether a given response is obtained, it is to be expected that different definitions of threshold (different responses required) would give different threshold db values However, the picture response method was supported by the very important criteria of interest on the part of the children and per cent of children who could be tested Gaining a child's interest, cooperation, and test thresholds are of major importance, both for clinical examination for a child he was asked which test he liked better, and which test he would like to have if he were to be tested again, also, the child's parents were sent a letter requesting them to ask their child prescribed leading questions about what happened in school that day, and to note his responses On the evening that a child was tested the parents were interviewed by telephone regarding their child's comments The child's statements to the examiner and the reports made by the parents were transcribed and presented to five disinterested judges The judges were asked to categorize each child's pattern of responses into the categories, "Definite preference for the standard test," "Slight preference for the standard test," "No preference," "Slight preference for the picture test," and "Definite preference for the picture test" These categories were assigned the numerical values 1 to 5 respectively, and the numerical values given each child by the five judges were totaled If the total for a child were more than 15 he was considered to have preferred the picture test, if less than 15 the picture test, and if it were 15 he was considered to have shown no preference By this procedure 91 per cent (30 children) showed preference for the picture response test, 3 per cent (one child) preferred the standard response test, and 6 per cent (two children) showed no preference

## DISCUSSION

As a result of these analyses the following conclusions can be drawn regarding each of the eight criterion for comparing the two test procedures

*1* For an initial clinical test of hearing acuity in the middle frequency range the picture response technique gives more acute thresholds than does the standard hand raising response technique The difference is about 3 db

*2* Reliability of the two test techniques appears to be about equal

*3* Orientation time for the picture response method is shorter than for the standard method For the present sample the difference was about one minute

*4* The picture response method is slightly advantageous dermal responses  Marcus and Gibbs, in 1948 and 1951, were the first to use electroencephalic responses to determine hearing  One study was reported by Gidoll in 1952  In 1953, Pearl, et al , reported again on the use of the E E G  responses in sleep to evaluate function of the ear  Since our first publication in 1956, Goldstein (1956) has reported on the use of the E E G  in conscious states as an auditory measurement, and Simon and Emmons (1956) have used these same endpoints

The original goal of all these workers was a clinical one concerning the many children under 4 and 5 years of age, and the many older ones in whom lack of communication is so serious a problem that standard methods do not work. With these patients it is important to be able to measure not only their functioning level, but also to dissect out where and what types of trouble may exist

From the data obtained by reliable standard audiometry it has been possible to infer where almost any disturbance may lie in the auditory system  These inferences, however, are only an approximation  They do not tell in a detailed way how any particular part of the system is abnormal, furthermore, reliable audiometry is most difficult to obtain in the child, where accuracy is most needed

It is during the diagnostic and planning states in the patient's early years that we need certainly to know whether the child's problem is in reception, in coding the information into nerve impulses, or in transmitting this information to the brain, or if the communication problem might also be higher up in the central nervous system involving the decoding process, the awareness, or the integration of this information with other knowledge and memories, so that synthesis into action or speech results (Hardy, 1956) , or if the delayed language might be due to psychic forces, so that the child finds that only a certain level of sound or speech is compatible with a comfortable existence  It might cost him too much emotionally to pay more attention, or invest more in the area of communication by sounds

For the evaluation of each of these components we need to and for further audiological work with the child In these respects the picture response method seems to have a clear advantage over the standard response method for testing preschool age children

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## FURTHER CONTRIBUTIONS TO THE E E G METHOD OF EVALUATING AUDITORY FUNCTION

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In the year 1939 the Davises first described the E E G responses to sound occurring in sleeping subjects This most accessible fact lay unused, except in animal work until 1948, when Doerfler used the E E G instrument to record electro-most common and most useful one we can identify Less often, instead of remaining suppressed, the pattern may gradually increase its voltage, rising to a level higher than that seen before stimulation This build up shows a latency of 0 5-1 0 sec

Third, there are frequent off-effects, of typical K formations, or brief periods of voltage reduction When working

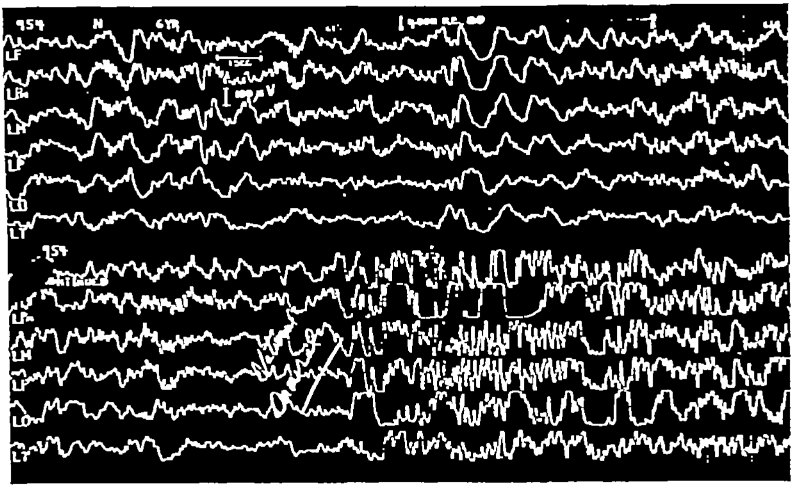

Fig 1 This E E G pattern shows three of the four possible responses to 5 seconds of pure tone The two strips are continuous. The E E G patterns are recorded between both ear lobes and LF (left frontal area) LPm (left precentral) LM (left central) LP (left parietal) LO (left occiput) LT (left mid-temporal) This is a normal hearing six-year-old patient. Arrows mark on and off of a 4000 c.p s tone at 80 db to the right ear A K formation begins after a latency of 0 8 seconds (on effect) There is a suppression of fast rhythms in frontal areas from 1 4 sec. to 3 6 sec. (continuous effect) although delta (1-2/sec.) persist. There is no off effect other than the return of 11/sec spindling with the cessation of tone Seventeen seconds after the stimulus starts there is a dramatic change of pattern signaling an arousal. The child woke up stirred and fell asleep again. The words 'natural arousal' written on the record were our notes meaning that no other stimulus was identifiable in the 17 sec. interval.

near threshold these are often stronger than the on-effect. Just as the conscious patient often misses the onset, but detects the turning off, of the presented tone when at or near threshold

Fourth, there is a late effect Any time within about 25 seconds of turning on a tone of 5 seconds' duration there may be a relatively sudden change in the entire pattern of the develop standardized methods that have a known reliability, and at the same time ease of accomplishment clinically.

The E.E.G. audio method in sleep, and in repose, offers procedures which put aside the psychic factors of making decisions. These electrical patterns tap the central nervous system after at least reception, coding and transmission have occurred. It is probable that the E.E.G. audio response is not at the synthesizing or motor levels. It is likely that these responses arise from a secondary pathway that splits off the main specific projection path for hearing somewhere in the brain stem or thalamus. This side path activates a diffuse system that in turn stimulates the cortex, both generally and specifically. The result is our E.E.G. response, and we believe an accompanying change in patients' sleep level. When the results of E.E.G. audio tests with known reliability are compared to standard audiometry, and to electrodermal audiometry, etc., then we can begin to establish where, to what degree and what kinds of information loss have occurred in our patient's communication channel.

Of primary importance is a careful description of the detectable responses used in E.E.G. audiometry in sleep. We began by searching for the K formations described by Davis. They were most clear and useful, but required a moderate to deep stage of sleep, and did not cover all of the various responses. They were better seen in response to clicks rather than pure tone. There were many times when a reduction of voltage or other changes were more apparent.

We find we can describe four component parts to the total response to a pure tone of two to six seconds' duration (see Fig. 1). There is, first, an on-effect with a latency of 50-500 msec. (average 250 msec.). This is most often a K formation, or a fragment of one or a spindle of 14/sec. waves. Whether or not a K formation occurs, there is, second, a reduction of voltage, particularly of the faster frequencies in the pattern with a latency of 200 to 600 msec. (average 400 msec.). This suppression may be brief or may continue throughout the 2 to 6 seconds the tone is presented. Although this is not the only kind of response at this point in time, it is by all odds the

These repeats were done because we were dissatisfied with the results on the first test for one reason or another Here again the variation was ±18 db We believe these express the worst possible errors in the method, and before giving a final statement we intend to describe more fully the nature of the most reliable response and the rules for its detection. We believe we can do better, because the consistency within one test is much better than the figure of ±18 db When there is deviation in our comparisons it is consistent and applies to all points in that test

Our first attempts to solve the reasons for these differences is the work we are reporting here We will describe these E E G responses as a function of intensity over a wide intensity range It should be emphasized that thresholds, regardless of their usefulness, are but a series of points along one edge of a vast field of sensory experience. A threshold is a function tested at its limits, where it is most likely to be non-linear At threshold the mechanism may function on some other principles than it would at the levels used for ordinary communication Finally a threshold is where error is likely to be greatest

There are two aspects of E E G responses which we can measure easily as functions of intensity one is the latency of the response, the other is percentage of positive responses identified at each intensity level, and these can be studied in repose and sleep states in the same patient In fact, on several occasions it has been possible to record on the 8 channel E E G machine a signal of the tone presented, a signal activated by the patient's closing a micro-switch held in his hand, the potentials of the muscles used for that action, the E E G, the E D G and either a pneumograph of the chest or a plethysmograph of a finger (see Fig 2) This record may start in repose, and after obtaining the function relating intensity to response, the patient may fall asleep, and we can repeat the function in sleep The percentage of positive responses as a function of intensity can then be compared in repose and sleep

It is often important to plot the latency in seconds as a

E E G, signifying a different level of sleep The subject may awaken at such a time, or the change may be only transient Rarely the E E G may show a deeper level of sleep

These responses do not all occur with every stimulus They may each vary in amplitude, duration and complexity, in fact, if one stimulus is repeated rhythmically, as Chafetz and Cadilhac (1954) have shown, the response tends to vary in complexity, amplitude, and ease of detection It comes and goes over periods of seconds to minutes Peculiarly, not all cortical areas wax and wane synchronously, so that the most clearly visible response may shift from area to area The form of the E E G responses show little evidence of relationship to intensity of stimulus as we test for them This relationship of form of response to intensity could well be masked by our method of study It is clear that since our latencies vary from the shortest of 50-70 msec to well over 2 0 seconds we are dealing with a complex system In fact, because the response is, *1* independent of age (down to 2 months), *2* has such a long and variable latency, *3* is most prominent in the fronto-central areas, we have proposed the idea that the response is evoked in the cortex, not by the primary projection path to the temporal lobe, but by a side path to the reticular formation of the midbrain or thalamus The question we cannot answer is whether or not every E E G change we identify could be heard by the patient if he were conscious and attending There is the possibility of sound arriving through the ear into the central nervous system that the patient could not consciously detect or hear

Accepting these E E G changes in sleep as responses to pure tone, the next question is what is the threshold of this E E G response, and what relations does it have to conscious hearing We define as threshold the intensity level producing 50 per cent positive response

The comparison of E E G threshold with standard audiometric thresholds in a group of children in a deaf school showed a deviation of ±18 db Recently we determined the variation between repeat E E G audiometric tests in sleep

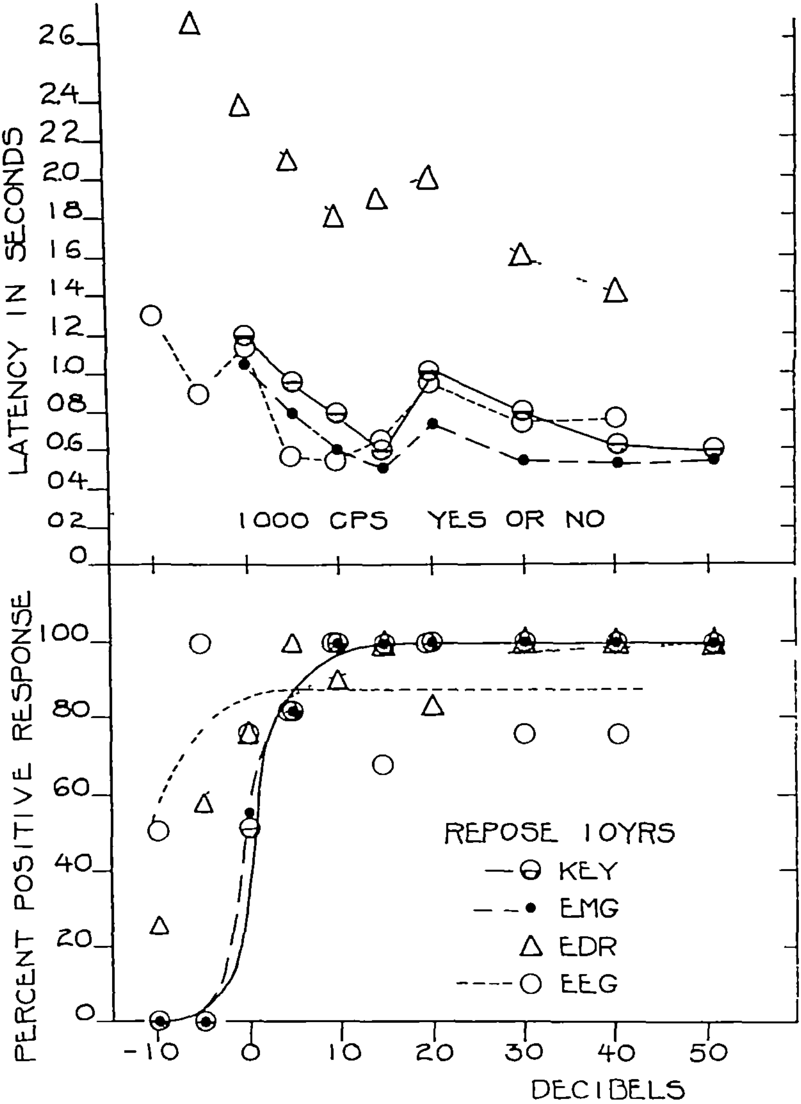

Fig 3 These are the plots of the latencies in the upper graph and the percentages of positive responses in the lower graph for 4 of the phenomena recorded polygraphically This data is obtained from the same patient in repose as shown in Fig 2 except that this is for 1000 c.p s to right ear Note that the latency of Alpha suppression is shorter than latency of muscle potentials till the level of 15 db is reached Above 15 db the muscle has the shorter latency

Key—Closure of micro-switch held in patient s hand E M.G—electromyal responses from the muscle group for flexing palm and fingers of hand holding key E D R.—Electrodermal responses as potential changes between palm and back of hand E E G—electroencephalic responses from leads covering frontal motor and occipital zones. Decibels in this paper are all relative to 0 db as the normal human threshold for that frequency function of intensity in decibels simultaneously with the per cent response curve Latency approaches infinite duration at some minimal intensity With increasing intensities the latency shortens until it approaches a minimal constant value This curve is so close to an hyperbola that if it is plotted as the reciprocal of the latency against intensity in decibels a straight line results Near threshold the points tend to deviate from the straight line function and may follow some different law, or it may be that since data is difficult to obtain at those low intensity levels in any quantity, inaccuracy makes results unreliable

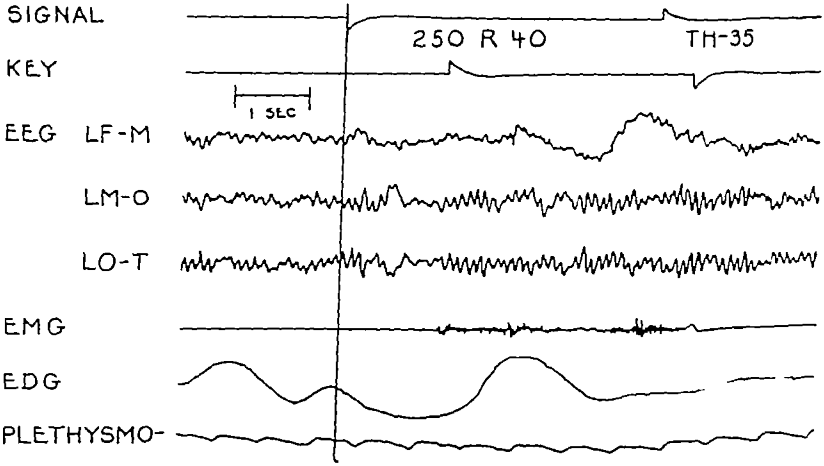

Fig 2 This is a strip of polygraphic recording from a patient in repose showing the responses to a tone of 250 c.p s to his right ear at 40 db or 5 db above his standard audiometric threshold The latency of closure of key is 1 4 seconds The latency of suppression of Alpha is 0 7 seconds The muscle potentials appear at 1 3 seconds The electrodermal response occurs at 1 9 seconds while the plethysmograph change occurs at almost 4 seconds With cessation of tone there is opening of key in 0 5 seconds and Alpha suppression in 1 3 seconds while the muscle potentials end in 0 35 seconds

By examining the functions of both latency and per cent response, it is more apparent when an error in reading has occurred In such a case the points at one sensation level on both curves deviate widely from the expected or smooth function By re-examining the raw data for these points one can learn about the errors in judgment likely to be made There is often wide variation around each point, but the consistency

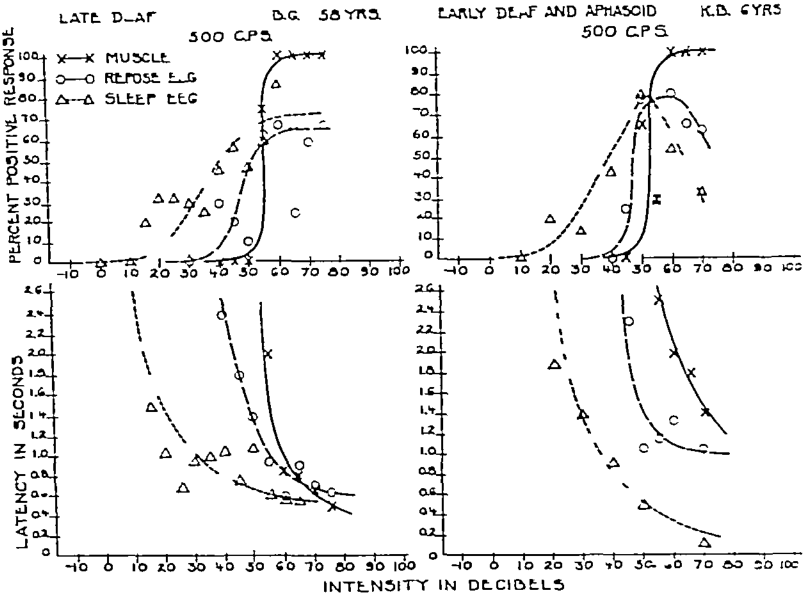

Fig 4-B

Fig 4 A-B This figure presents the plots of latencies in the lower curves and of the percentages of positive responses in upper curves The three individual curves represent the E E G responses in sleep the suppression of Alpha in the E E G of repose and either the muscle potentials or closure of key in repose The four patients are A. G a normal O M middle aged patient with otosclerosis of some eight years duration B. G an elderly person with deafness occurring late in life on the side being tested and K. B a young child who clinically has evidenced both deafness and language retardation since the age of speech development. These functions were all studied at 500 c.p s

The reversal of latencies between Alpha suppression and key is not seen in all patients in the range studied The functions of the unconscious responses (E.E G ) arrive at a maximal percentage and minimal latencies about the intensity level at which the conscious response is making its most rapid changes.

On patient K. B is indicated a phenomenon which is not rare The per cent of positive E E G responses falls off at intensities higher than those which achieve the maximum. This suggests inhibitory phenomena. (Hardy 1957)

when working at minimal intensities It is most obvious that the subject hears, even though he decides not to respond

At minimal levels of intensity the suppression of Alpha appears as the first response in time and the muscle potentials come later in time About 20 db above this level there is a trend for reversal The muscle potentials appear first and the Alpha suppression follows We assume that the Alpha activity is suppressed by an increase in attention In the light of this concept, then, the Alpha suppression would be with which the averages yield the same shape of curve convinces us of the presence of the two functions at this low intensity edge of the auditory field

The comparison of these functions with different kinds of communication problems, and the comparison of repose and sleep, bring out information about our original problem of the differences between standard and E E G audiometry

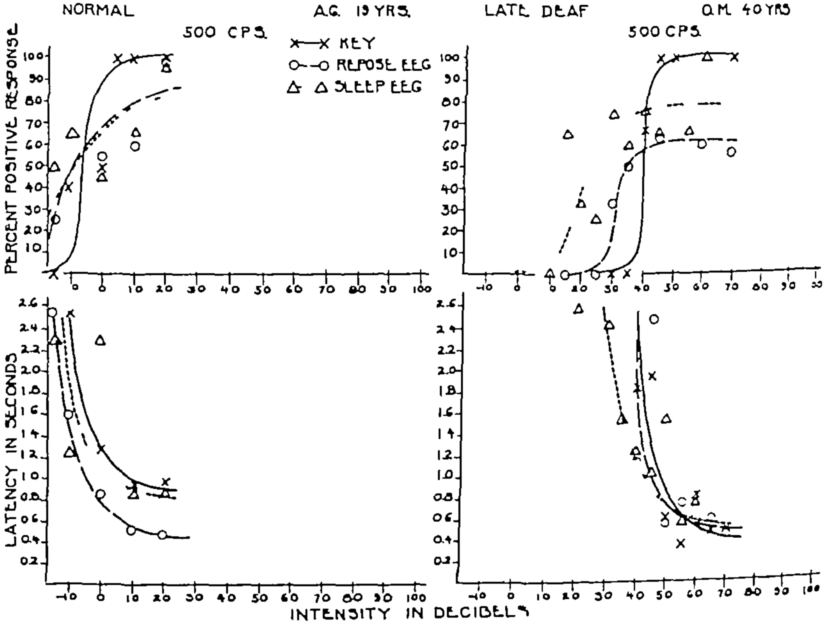

Fig 4-A

An illustration of these functions as displayed by the various end points of response in the waking normal subject are illustrated in Fig 3

The unconsciously controlled components i e, E E G and E D G tend to show a higher percentage of positive responses and shorter latencies than those of the E M G and the key at low intensity levels These responses may reflect the presence in the central nervous system of the information upon which the closing of the key is made It is of interest to see the presence of muscle tension without closure of key mum It appears that the conscious audiometric threshold is the level at which near maximal alertness has been achieved by the tone

J J Groen (1957) has suggested that these curves represent probability functions, in which the coincidental presence of the first two (E E G response in sleep and in repose) might represent activities in the nervous system which cause the third (response of the key) It seems as though each function might represent a nucleus on the way to the cortical surface

The response of the key would reflect cortical activity The Alpha suppression in repose would reflect the action of some nucleus below the cortical level, perhaps in the thalamus The E E G responses in sleep would reflect a still deeper nucleus or center perhaps in midbrain

## SUMMARY

The characteristics of responses to tone in the E E G in sleep are reviewed On, continuous, off and late effects are described

The latency of the first identifiable response, and the per cent positive responses are studied as functions of intensity

Three functions are compared

*1* In sleep those described above (an unconscious response)

*2* In repose the Alpha suppression (an unconscious response)

*3* In repose the closure of a key (a consciously determined decision)

The function of per cent positive responses in sleep has the most gradual slope, while the closure of the key has the steepest slope

The latency at minimal intensities is shortest for the E E G response in sleep, while it is longest for closure of key The difference is lost, or the reverse is true at the higher intensity levels much more likely at low intensity levels, where the signal is hardly distinguishable from the background noise, and an increase in attention is required for detection of the sound When the tone is 20 db stronger, then no change in attentiveness is required for detection, so the Alpha may not suppress, however, we often now find the Alpha suppressed after the appearance of the muscle potentials for closing the key It is probably the increase in alertness resulting from the movement which produces this Alpha suppression

In Fig 4 are shown four pairs of these same curves of latency and per cent positive response related to intensity for four persons (one normal and one deaf from otosclerosis, one deaf late in life and one child with both aphasia and deafness) In each graph are presented simultaneously the three curves found for the key or muscle response, the suppression of Alpha in repose and the E E G response in sleep

The relationships between these three measurements indicates that the consciously determined response of muscle or key has a shift from 0 to 100 per cent positive response over only a narrow intensity range The E E G response in repose has a less steep slope, and rises over a broader intensity range, while the E E G response in sleep has a still more gradual rise or slope The trend, however, is for the E E G functions to arrive at their maximum per cent at the same intensity level at which the key or muscle response suddenly rises to its maximum

The function of the muscle, or key response, expresses the probability of occurrence of a conscious decision This decision is determined by many factors, which are at present being investigated by W Tanner (1956) Over and above the signal to noise ratio these factors include the various values and costs of correct and erroneous judgments within the situation The decision also depends upon the clarity in the patient's memory of the tone for which he is listening, as well as his ability to listen

Since the E E G functions are a correlate of alertness and arousal, it is significant that these reach their maximum at the time when the key response makes its rapid rise to maxi-

## SESSION B

May 16, 1957

# BEHAVIOR OF THE NEUROGLIA OF THE ACOUSTIC NUCLEI, SUB-CORTICAL CENTERS AND AUDITORY CORTEX, OF CATS INTOXICATED WITH DIHYDRO-STREPTOMYCIN

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Neurotoxic phenomena caused by the use of antibiotics, are well known, however, the specific toxicity of streptomycin for the vestibular system, and of dihydro-streptomycin for the cochlear system, is interesting Literature on the subject is wide, and we should like to remember the papers of Fowler and Seligman[1], Carr, Brown, Hodgson, and Heilman[2], Shane and Laurie[3], Glorig[4], Heck, Lynch and Graves[5], Caussé[6], etc

Considering the neurotoxic phenomena doubtless induced hematically, we tried to verify the behavior of the nourishing element of the nerve tissues, the neuroglia, in the several nuclei of the cochlear pathway, the sub-cortical centers and in the auditory cortex No reference was found to this important complement of the nervous tissue in more than 40 bibliographic sources Taking advantage of the known specific toxicity of dihydro-streptomycin for the cochlear system, we endeavored to bring some light to the confused cochlear pathway and cortical projection on an experimental animal Unable to use the monkey, we chose the cat, whose nervous system has been thoroughly investigated

## ANATOMIC AND PHYSIOLOGIC DATA

Stimuli received by the organ of Corti pass the dorsal and ventral cochlear nuclei, from there they go through the

The E E G response in sleep and the Alpha suppression in repose are interpreted as signs of alerting mechanisms of the reticular formation These functions reach their maximum at the same intensity level at which the per cent response for the closure of the key reaches its maximum This suggests that maximal alertness is one element in determining the standard audiometric threshold

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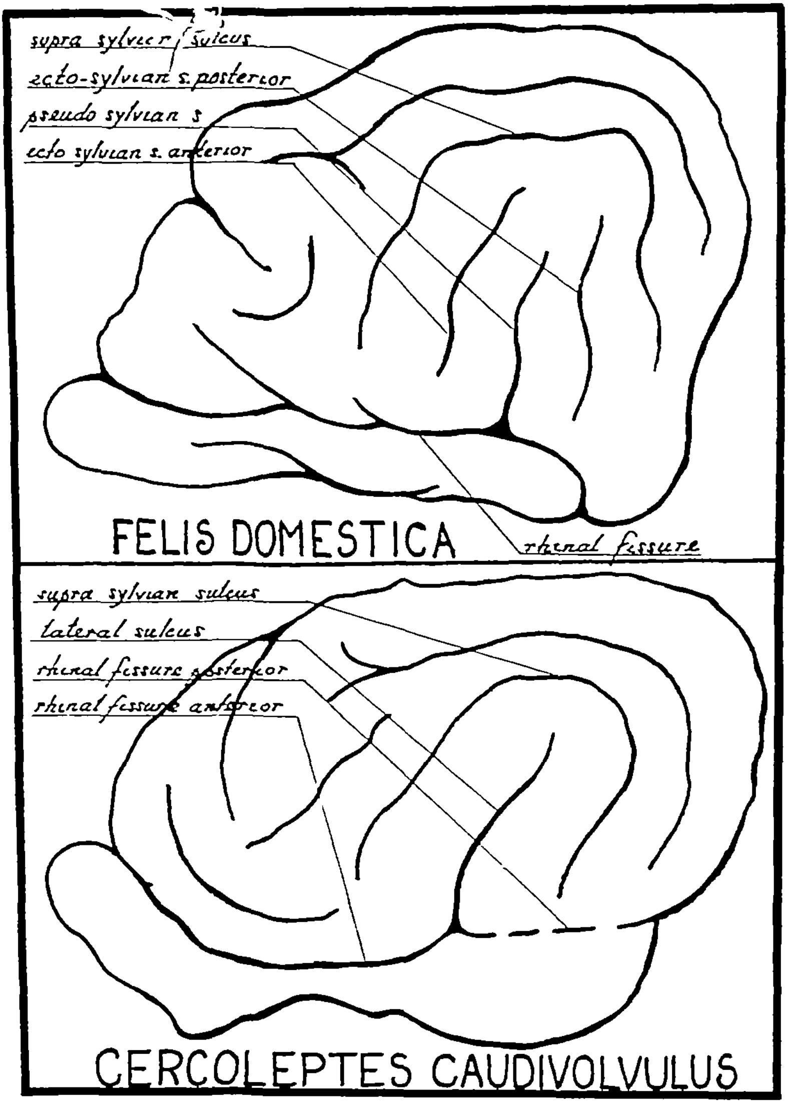

Fig 1

letti, 1915[19], Loreti, 1938[20], Bairati, 1950[21], and Contu, 1953[22], by the Anglo-American School, Penfield, 1924[23], and Robertson, 1900,[24] and by the German School, Nissl, 1904, and Bauer, 1924 [25] superior olive, trapezoid body nucleus and the opposite lateral lemniscus nucleus to the inferior colliculus (posterior quadrigeminal tubercle) and to the medial geniculate body, which also receives stimuli from the inferior colliculus and from fibers of the opposite nerve, through the so-called Gudden commissure (Castaldi, 1920[7]) It is evident, that the inferior colliculus has a double action *a* Interposed center in the superior pathway, *b* Reflex center Cochlear reflex movements of the eyes and neck are so determined It is, therefore, established that the true acoustic sub-cortical center is on the medial geniculate body, where the acoustic radiation that goes to the cortex originates (Becarı, 1943[8])

The center of the acoustic projection is little known in experimental animals In the human, it is localized above the the superior temporal gyrus, (Pfeifer, 1920[9]), and constituted by separated striae organized in different physiologic zones, placed according to Campbell[10] and Penfield[11] on the areas 22, 41, 42 of Brodman's chart

Walker[12] described the acoustic projection on the monkey Very little is known about the other vertebrates, including the cat, besides Cajal's (1911) demonstration of elements that were similar to the acoustic cells of man [13] Functional localizations were well observed on the carnivora, but the uncertainty about the acoustic area remained, due to the poorly defined relations of the temporal sulci The disagreement among writers reached its peak regarding the identification of the so-called ecto-sylvian sulcus

Fig 1 shows the lateral views of the brain of the cat, according to Dusser de Barenne[14] and of the cercoleptes caudivolvulus, according to Brodman [15] The morphologic difference of the topographical arrangements of the sulci of the temporal lobe, mainly the ecto-sylvian sulcus, is clear In the cat, the sulcus is called pseudo-sylvian and located in front, of the anterior ecto-sylvian sulcus and behind the posterior ecto-sylvian sulcus

The well-known neuroglia was mainly studied by the Spanish School, Cajal, 1911, 1920[13], Rio Hortega, 1921, 1942[16], De Castro, 1942[17], by the Italian School, Golgi, 1903[15], Ceranimals had their weight and cochlear reflexes controlled every two days The animals were sacrificed by perfusion of the Del Rio-Hortega liquid Distilled water, 240 cc , Formalin, 60 cc , Ammonium bromide, 9 gr , pH = 5

The fixation was controlled daily, and the solution changed every time it became neutral After 15 days of fixation the specimens were frozen-sectioned and submitted to impregnation for 30 days

CHART I
DI HYDRO STREPTOMYCIN INTOXICATION

| DAY | CAT N 1 | | | CAT N 3 | | | CAT N 5 | | | CAT Nº 6 | | | CAT Nº 8 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | — | WEIGHT IN GRAMS | ACOUSTIC REFLEXES | [illegible] | WEIGHT IN GRAMS | ACOUSTIC REFLEXES | [illegible] | WEIGHT IN GRAMS | ACOUSTIC REFLEXES | [illegible] | WEIGHT IN GRAMS | ACOUSTIC REFLEXES | [illegible] | WEIGHT IN GRAMS | ACOUSTIC REFLEXES |
| 5 23-56 | | 1350 | PRESENT | 0.10 | 1800 | PRESENT | 0.10 | 1750 | PRESENT | 0.10 | 1250 | PRESENT | 0.10 | 1700 | PRESENT |
| 5 24 56 | | | - | 0.10 | | - | 0.10 | | - | 0.10 | | | 0.10 | | |
| 5 25 56 | | 1350 | - | 0.10 | 1635 | - | 0.10 | 1750 | | 0.10 | 12 0 | - | 0.10 | 1750 | - |
| 5 26 56 | | | - | 0.10 | | - | 0.10 | | | 0.10 | | MODERATE | 0.10 | | - |
| 5 27 56 | | | - | 0.10 | | MODERATE | 0.10 | | | 0.10 | | | 0.10 | | |
| 5-28 56 | | 1428 | - | 0.10 | 1795 | - | 0.10 | 1820 | MODERATE | 0.10 | 1325 | | 0.10 | 1 5 | MODERATE |
| 5 29 56 | | | - | 0.10 | | - | 0.10 | | - | 0.10 | | - | 0.10 | | |
| 5-30 56 | | 1450 | - | 0.10 | 1820 | - | 0.10 | 1870 | - | 0.10 | 1400 | - | 0.10 | 1825 | - |
| 5 31 56 | | | - | 0.10 | | - | 0.10 | | - | 0.10 | | FAINT | 0.10 | | |
| 6 1 56 | | 1500 | - | 0.10 | 1560 | FAINT | 0.10 | 1900 | - | 0.10 | 1430 | - | 0.10 | 1950 | FAINT |
| 6 2 56 | | | - | 0.10 | | - | 0.10 | | - | 0.10 | | | 0.10 | | |
| 6 3 56 | | | - | 0.10 | | ABSENT | 0.10 | | FAINT | 0.10 | | - | 0.10 | | - |
| 6 4 56 | | | - | 0.10 | | - | 0.10 | | - | 0.10 | | | 0.10 | | |
| 6 5 56 | | | - | 0.10 | | - | 0.10 | | | 0.10 | | ABSENT | 0.10 | | - |
| 6 6 56 | | | - | 0.10 | | - | 0.10 | | | 0.10 | | - | 0.10 | | |
| 6 7 56 | | | - | 0.10 | | [illegible] | 0.10 | | - | 0.10 | | | 0.10 | | ABSENT |
| 6 8 56 | | 1450 | - | 0.10 | 1650 | - | 0.20 | 17 0 | - | 0.20 | 1350 | | 0.20 | 1650 | - |
| 6 9 56 | | | - | SACRIFICED | | | 0.20 | | ABSENT | 0.20 | | - | 0.20 | | - |
| 6 10 56 | | | - | | | | 0.20 | | - | 0.20 | | [illegible] | 0.20 | | |
| 6 11 56 | | | - | | | | 0.20 | | [illegible] | 0.20 | | - | 0.20 | | |
| 6 12 56 | | | - | | | | 0.20 | | - | SACRIFICED | | | 0.20 | | [illegible] |
| 6 13 56 | | | - | | | | SACRIFICED | | | | | | 0.20 | | |
| 6 14 56 | | SACRIFICED | | | | | | | | | | | SACRIFIC | | |

The Del Rio-Hortega method as used in the Anatomy Laboratory of the University of Recife includes the following rules

1 After life fixation by perfusion, excision of the nervous system with dissection of the pons, medial geniculate body brachium of the inferior colliculus, inferior colliculus, and cortex, corresponding to the gyri in front, and behind to the pseudo-sylvian sulcus Specimens obtained were submitted to fixation for 15 days in the Rio-Hortega liquid

2 Frozen sections, 15 to 25 micra thick

Barrati and Contu established the glial architecture of the nervous centers, the former in the amphibia and avis, and the latter in the reptilia and mammalia These authors proposed the following classification

*Type 1* Architecture of the white substance gliocytes arranged around the myelin sheath, bound among themselves and with the vascular net, by other glial elements, forming a connective apparatus

*Type 2* Architecture of the brain stem nuclei gliocytes forming perineuronal sheaths arranged as a connective apparatus with the blood vessels

*Type 3* Architecture of the supra axial centers gliocytes articulated with the glial processes and with the vessels

Studying the medulla oblongata of the cat, Contu found glial architecture of the second type, formed by fibrous elements with numerous satellite oligodendrogliocytes In the inferior colliculus the same aspect was seen innumerable oligodendrogliocytes with regular cuboid body, thin, smooth, hairlike processes, scarcely ramified In the young animals, however, the architecture is constituted by protoplasmatic elements, also scarcely ramified, epithelioid elements and small oligodendrogliocytes The former aspect, according to the author, would be the result of age

Some authors reported glial intoxication Among them, Sancez Ibañez and Perez[26] in 1935 performed guanidinic intoxication and observed gliosis and granular degeneration of the processes' cytoplasma

Stigliani[27] in 1940, demonstrated in the toxi-infections a great amount of neuroglia, and writes about glial hyperplasia without any statistical proof, as reported before by Lucaro[28] in 1907, even though affirming that mitosis and amitosis were exceptional on the neuroglia

## MATERIAL AND METHODS

Five cats, two male and three female, between eight and 18 months old, were used Meat and milk were their diet One of the cats was used as a control (see chart) The

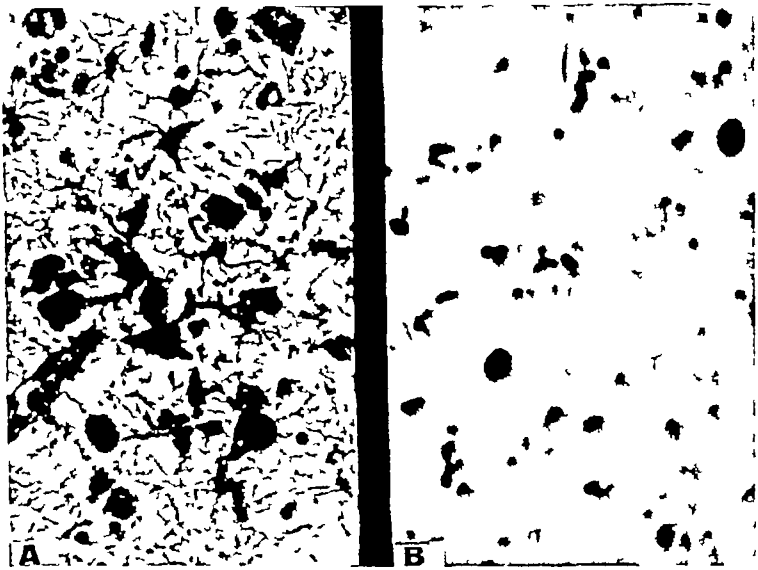

Fig 2
A—Section of cochlear ventral nucleus of control cat—500X.
B—Section of cochlear ventral nucleus of intoxicated cat—500X.
(Del Rio-Hortega Method)

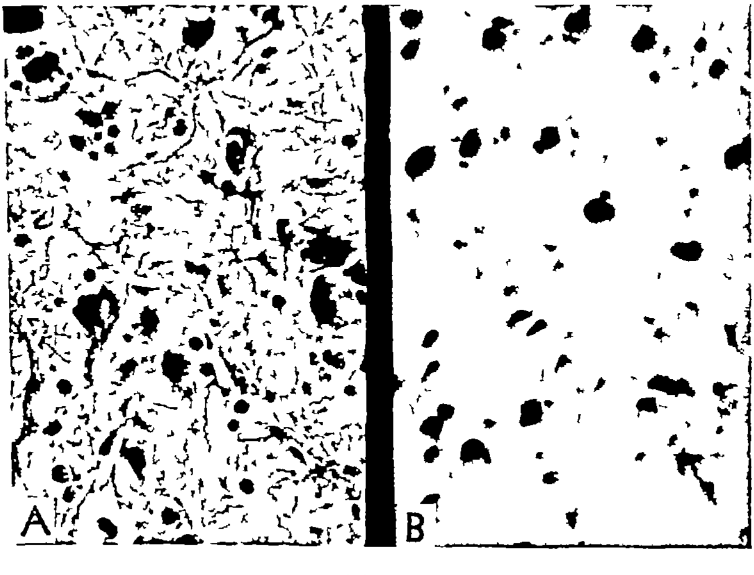

Fig 3
A—Section of trapezoid body of control cat—500X.
B—Section of trapezoid body of intoxicated cat—500X.
(Del Rio-Hortega Method)

*3* Re-fixation in the Rio-Hortega for 15 days

*4* Washings for one hour in three distilled waters

*5* Sections submitted to Hortega's silver, to which was added two to four drops of piridin, for one hour at ambiental temperature, and for 10 to 20 minutes at 50° C

*6* Washing for 30 minutes in distilled water

*7* Reduction in formaldehyde solution by 5 per cent

*8* Washing for one hour in distilled water

*9* Turning over of the specimens in a solution of 2 per cent of gold chloride

*10* Fast washing in distilled water

*11* Reduction for five minutes in a 5 per cent solution of sodium hyposulfite

*12* Washing for one hour and alcoholic dehydration followed by mounting of the specimens in Canada balsam

Some of the specimens have also been submitted to the Mallory and Iron Hematoxilin methods

## EXPERIMENTAL FINDINGS

Sections of the pons, (cochlear nuclei, superior olive, and trapezoid body nucleus), mesencephalon, (inferior colliculus), metathalamus, (medial geniculate body) and cortex, (gyrus between the pseudo-sylvian sulcus and the posterior ectosylvian sulcus), were studied

### *Pons*

Control Cat—Glial architecture of the second type was found on the cochlear nuclei, superior olive and trapezoid body Perineuronal sheath formed by fibrous astrocytes and satellite oligodendrogliocytes nicely developing connective apparatus and connections with the blood vessels (see Figs 2, 3)

Intoxicated Cats—Only the nuclei of the gliocytes appear, many with abundant atypical mitosis The glial processes are not demonstrable, and only a few oligodendrogliocytes present thin processes, almost unimpregnated, mitosis more frequent on the gliocytes of the connective apparatus

*Mesencephalon*

Control Cat—Typical second type architecture on the inferior colliculus Big fibrous astrocytes with many ramifications Many oligodendrogliocytes with thin and smooth processes with little protoplasmatic elements (see Fig 4)

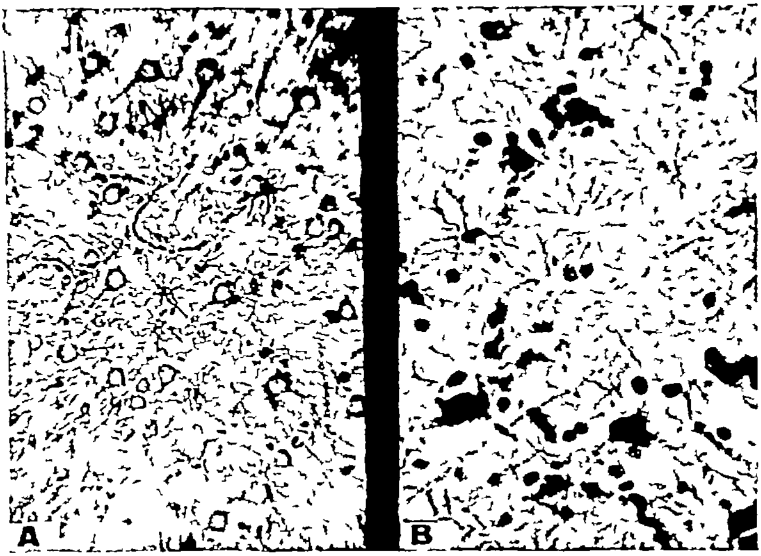

Fig 5

A—Section of geniculate body of control cat—145X.
B—Section of geniculate body of control cat—500X.
(Del Rio-Hortega Method)

Intoxicated Cats—A very different aspect, atypical mitosis and only in very few elements the processes appeared slightly impregnated, most of the processes are non-identifiable

*Metathalamus*

Control Cat—Glial architecture of the geniculate body of second type, characterized by the presence of few fibrous astrocytes, many protoplasmatic processes and oligodendro-

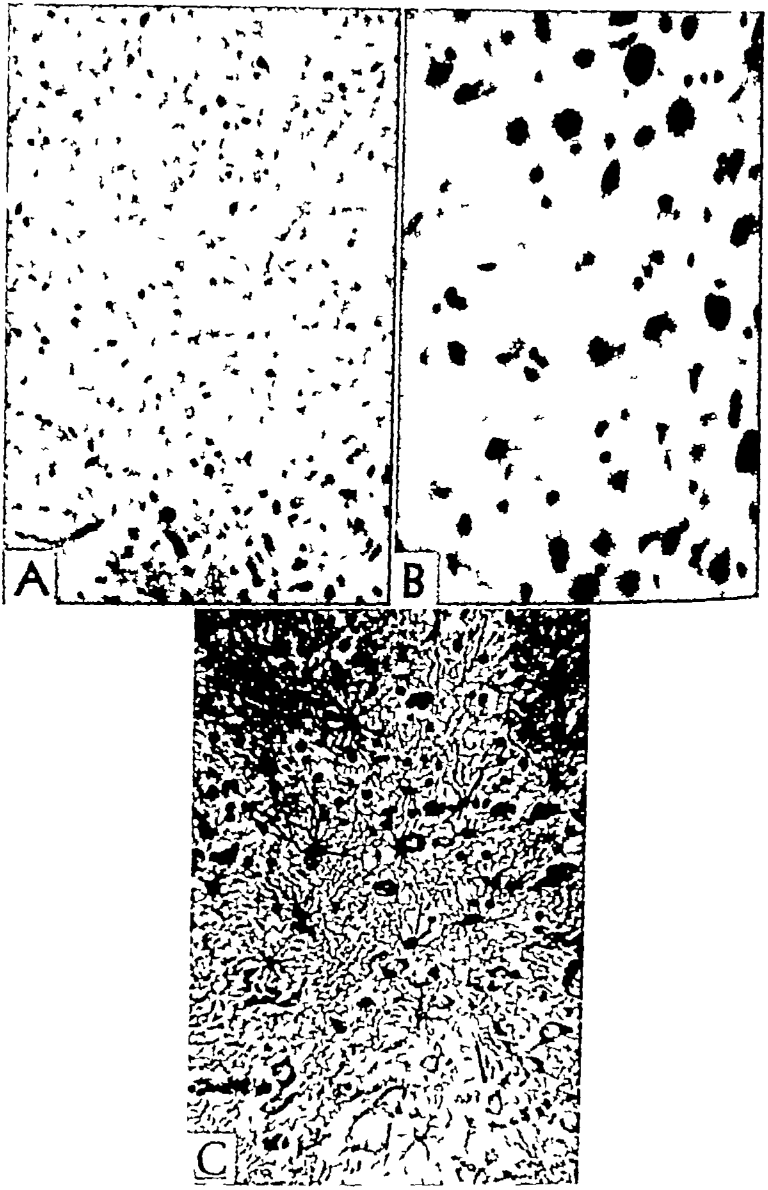

Fig 4

A—Section of inferior colliculus of intoxicated cat—80X.
B—Section of inferior colliculus of intoxicated cat—500X.
C—Section of inferior colliculus of control cat—145X.
(Del Rio-Hortega Method)

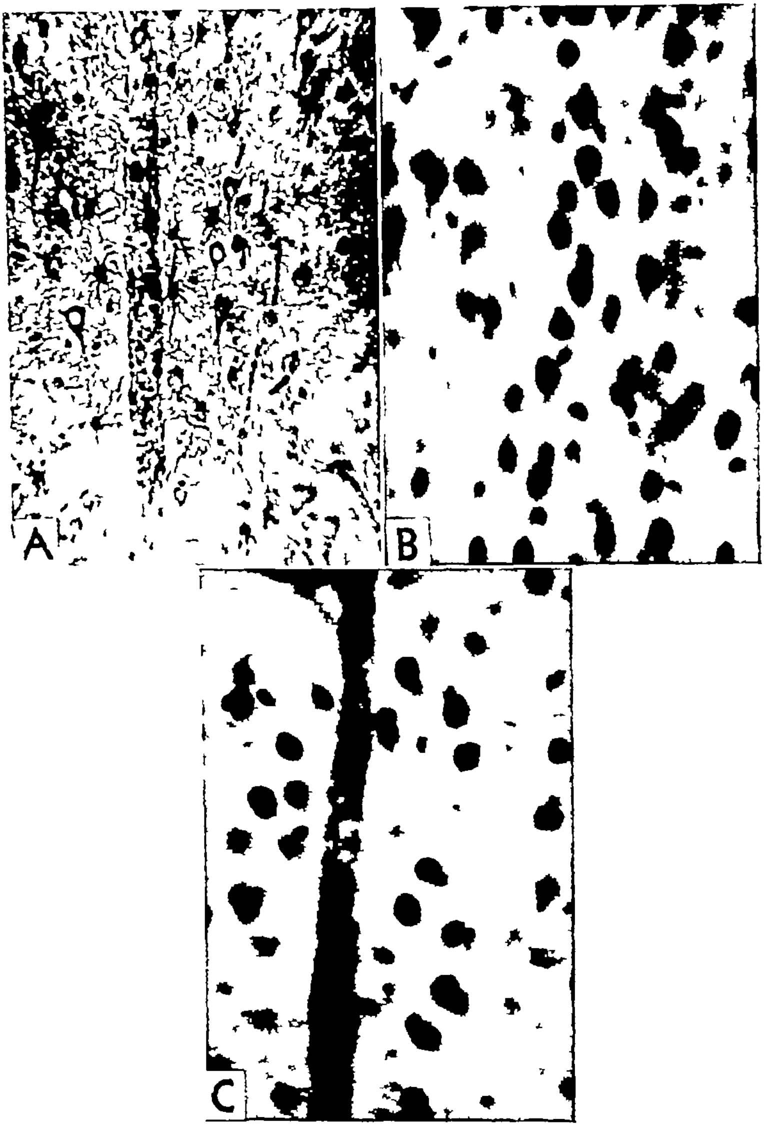

Fig 7

A—Section of the gyrus behind the pseudo-sylvian sulcus of control cat—145X.

B and C—Section of the gyrus behind the pseudo-sylvian sulcus of intoxicated cat—500X. (Del Rio-Hortega Method)

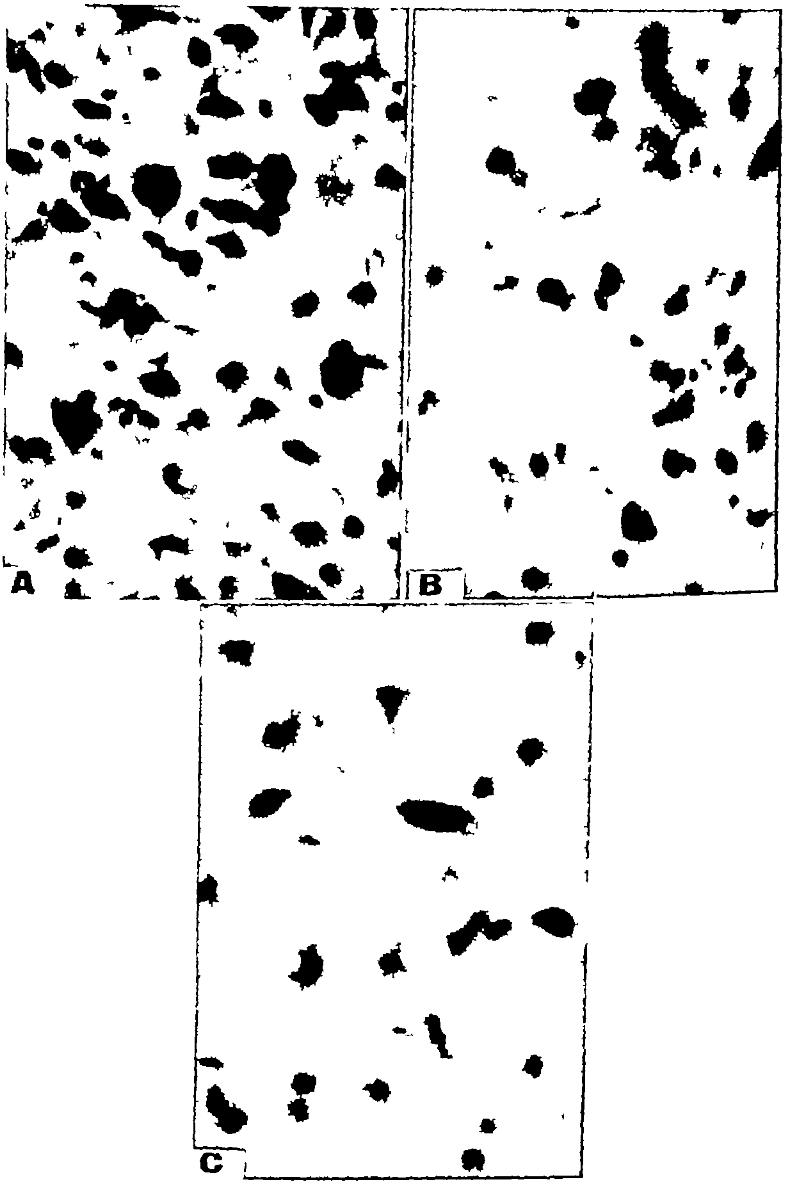

Fig 6

A—Section of central area of geniculate body of intoxicated cat—500X
B and C—Section of marginal area of geniculate body of intoxicated cat—500X. (Del Rio Hortega Method)

be detected only on the molecular striatum, even though not so evident as in the control cat

*Spinal Cord, Brain Stem and Areas of the Cortex*

Control Cat—Normal glial architectures

Intoxicated Cats—The spinal cord shows normal glial architecture, less evident glial architecture was found in the boundaries of the pons, in the brain stem as well as in other areas of the pons themselves, as much in the white substance as in the gray, sections of the frontal, parietal and occipital cortex showed no alteration of the glial structures

## CONSIDERATIONS AND CONCLUSIONS

Objections could be made to this experiment on the basis of the known lability of the glial structures under silver impregnation Celletti[19] in 1915 denied the existence of the glial processes That opinion was, however, due to the difficulty of impregnation of glial structures permitting the appearance of technical artifacts Different aspects of neuroglia observed under similar conditions have been reported by Cardona,[29] and Stigliani[27] assumed that the general conditions of the material would rule the glial demonstrability Based on this assumption he explained the phenomenon of glial phanerosis, which would not be hyperplasia, but only better identification due to self and surrounding conditions Doubtless this phenomenon is more evident in the cortex, and we found it in the gyrus behind the posterior ecto-sylvian sulcus giving the impression of gliosis On the other hand we found that in the gyrus behind the pseudo-sylvian sulcus the glial structure disappeared, leaving only the cellular bodies, many of which presented mitosis It seems evident that areas so closely placed and so deeply differentiated must be under different metabolic conditions This must also be the reason for the various observations of the neuroglia

We cannot say which is the true toxic action of the streptomycin over the neuroglia in the observed areas whether the alterations are definitive or transitory, or whether this toxicity acts on the neuroglia alone, but we can affirm the fact that this toxic action reaches the feeding elements cytes with small processes, several gliocytes without any processes Transitional elements were found here between protoplasmatic and fibrous processes (see Figs 5, 6)

Intoxicated Cats—Many atypical mitosis of the gliocytes, very few impregnated processes could be found

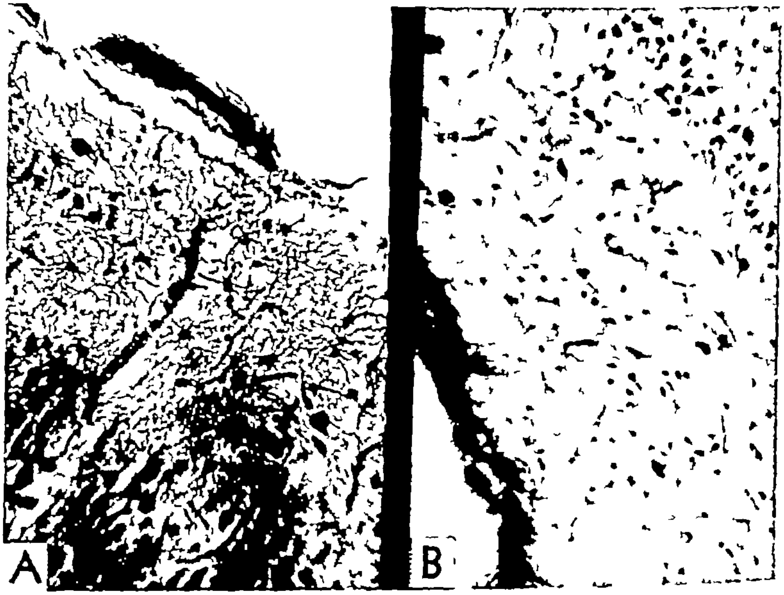

Fig 8

A—Section of molecular stratum of the gyrus behind the pseudo-sylvian sulcus of control cat—145X

B—Section of molecular stratum of the gyrus behind the pseudo-sylvian sulcus of intoxicated cat—80X. (Del Rio-Hortega Method)

*Auditory Cortex*

Control Cat—Glial architecture of the third type Fibrous and protoplasmatic astrocytes, many oligodendrogliocytes with cuboid body and smooth and hairlike processes (see Figs 7, 8)

Intoxicated Cats—Glial architecture too evident in the gyrus behind the posterior ecto-sylvian sulcus seeming a gliosis, while in the gyrus behind the pseudo-sylvian sulcus the gliocytes show no processes and some mitosis Processes could called phanerosys and glial-reaction expressed by intense mitotic activity, which is seen mainly in the geniculate body Glial phanerosys and mitosis are also visible in the girus behind the pseudo-sylvian sulcus, permitting the author to assume the hypothesis of this being the cortical center of the acoustic radation

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of the nerve cells, inducing glial mitosis with lack of impregnation of the glial processes

Our observations need further histological and cytochemical basis It is our intention to repeat the experiment and study the material with a polarizer microscope to observe eventual modifications of the refringency of the processes This, we understand, would give a better answer as to the destiny of the processes We also think it necessary to verify the number of glial nuclei statistically, and so prove the existence of hyperplasia, also, we wonder whether the processes would remain impregnated if submitted to more intensive fixation

With the data obtained in our experiment we can, however, conclude that the dihydro-streptomycin exerts toxic action on the centers of the cochlear pathway, as shown by atypical glial mitosis and disappearance of glial structures, well demonstrated in specimens taken from a control animal, treated with the same technical approach, furthermore, the presence of mitosis and the absence of glial processes in one area of the gyrus behind the pseudo-sylvian sulcus, permits us to assume that this is the site of central acoustic radiation in the cat

## SUMMARY

Employing the silver impregnation method of Del Rio Hortega, the Mallory and the Iron-hematoxylin methods, the author studies the neuroglia of the nuclei of the cochlear pathway (ventral and dorsal cochlear nuclei, superior olive, trapezoid body nucleum and lateral lemniscus nucleum), the sub-cortical acoustic centers (tuberculum quadrigeminus inferior and medial geniculate body) and the cerebral cortex concerning the gyri in front of and behind the pseudo-sylvian sulcus, presumed area of representation of the acoustic radiation, in four cats, intoxicated with daily doses of 0 10 to 0 20 grams of dihydro-streptomycin, applied parenterally for 17 to 22 days One cat was used as control

The glial architecture was found disorganized in the nuclei of the cochlear pathway and in the sub-cortical centers The neuroglia cells appear with protoplasmatic processes not easily identifiable In some cases it is visible, the phenomenon so-

tion of the internal spiral with the intraganglionic spiral fibers, whose real origins are in the superior olivar peduncle, forming the so-called Rasmussen bundle.[3,4] These fibers are directed to the internal acoustic cells which, therefore, receive double nerve supply, afferent and efferent.

Rasmussen's description was confirmed by Fernandez[5], Portmann[6], Contu and Pirodda[7], and Fierre deBarros[8], while Bocca[9,10], Palumbi[11] and Del Bo and Livan[12,13], expressed the opinion that the spiral fibers were from sympathetic or vestibular origin, reminding us of the so-called cochleo-vestibular anastomosis, described by Boettcher,[14] Bovero,[15] Oorth,[16] Weston and Mesolella.[17] Considering the external fibers, Held[18] and Kolmer[19] agree on their course and termination in the external acoustic cells.

Very little emphasis has been placed upon the ganglion of Corti and with the exception of Fort,[20] the majority of writers place the ganglionic cells in the Rosenthal canal. Writers limit themselves to the description of the cochlear nerve as a bundle of axons pertaining to the ganglion of Corti's bi-polar cells. As a rule, neuroglia was found on its first segment, 6 to 8 mm. from its apparent origin.[21]

Many years ago, Hyrtl, Stannius, Kolliker and Pierret[22] found cells on the surface and interior of the acoustic nerve, and Erlisky[23] and Fort,[20] and recently Chiarugi,[24] described cellular elements in the vestibular branch of the VIIIth nerve, arranged in groups as in the principal ganglia.

We used the cat as experimental animal, intravitally fixed with Rio Hortega's or De Castro's formulas. The whole temporal bone was removed with the acoustic nerve up to the rhombencephalon. Specimens were submitted to electrolytical decalcification and silver impregnated, by the Cajal De Castro, Bodian and Rio Hortega metohds. Frozen sections were made from those under Cajal De Castro and Bodian impregnation, and colloidan-paraffin-fast inclusion permitted us to obtain a complete seriation from the cochlear to the rhombencephalon.

We reached the following conclusions:

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# OBSERVATIONS AND CONSIDERATIONS ABOUT THE COCHLEAR INNERVATION OF THE CAT

PAOLO CONTU,

University of Recife, Brazil

Incomplete anatomical bases have been the cause of many hearing theories, therefore, problems concerning cochlear innervation are doubtless important

In our laboratory of Microscopic Anatomy we are considering the cochlear nerve problem, establishing systematic research under the most modern methods and techniques, and considering not only the organ of Corti but also the whole acoustic system

Careful revision of available literature demonstrates different distribution of peripheric cochlear nerve fibers among man and other mammals

Lorente de Nó's[1,2] classical division of nerve fibers in radial, external spiral, internal spiral and intraganglionic spiral fibers, was lately substantially modified by identifica-

tion of the internal spiral with the intraganglionic spiral fibers, whose real origins are in the superior olivar peduncle, forming the so-called Rasmussen bundle[3,4]. These fibers are directed to the internal acoustic cells which, therefore, receive double nerve supply, afferent and efferent.

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29 Cardona Referred to by Bairati[21]

# OBSERVATIONS AND CONSIDERATIONS ABOUT THE COCHLEAR INNERVATION OF THE CAT

Paolo Contu,

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Incomplete anatomical bases have been the cause of many hearing theories, therefore, problems concerning cochlear innervation are doubtless important

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Careful revision of available literature demonstrates different distribution of peripheric cochlear nerve fibers among man and other mammals

Lorente de Nó's[1, 2] classical division of nerve fibers in radial, external spiral, internal spiral and intraganglionic spiral fibers, was lately substantially modified by identification of the internal spiral with the intraganglionic spiral fibers, whose real origins are in the superior olivar peduncle, forming the so-called Rasmussen bundle[3,4] These fibers are directed to the internal acoustic cells which, therefore, receive double nerve supply, afferent and efferent

Rasmussen's description was confirmed by Fernandez[5], Portmann[6], Contu and Pirodda[7], and Freire deBarros[8], while Bocca[9,10], Palumbi[11] and Del Bó and Livan[12,13], expressed the opinion that the spiral fibers were from sympathetic or vestibular origin, reminding us of the so-called cochleo-vestibular anastomosis, described by Boettcher,[14] Bovero,[15] Oorth,[16] Weston and Mesolella[17] Considering the external fibers, Held[18] and Kolmer[19] agree on their course and termination in the external acoustic cells

Very little emphasis has been placed upon the ganglion of Corti and with the exception of Fort,[20] the majority of writers place the ganglionic cells in the Rosenthal canal Writers limit themselves to the description of the cochlear nerve as a bundle of axons pertaining to the ganglion of Corti's bi-polar cells As a rule, neuroglia was found on its first segment, 6 to 8 mm from its apparent origin[21]

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3. The Rasmussen bundle is very evident on the base of the lamina espiralis, its fibers composing the internal spiral fibers, a continuation of the intraganglionic ones. As previously demonstrated by Fernandez, they do not exclusively innervate the internal acoustic cells, but many turn backwards to the sustaining cells and from there are directed to the base of the limbus espiralis. Portmann[25] already described nervous fibers of sensitive aspect in the limbus laminae espiralis.

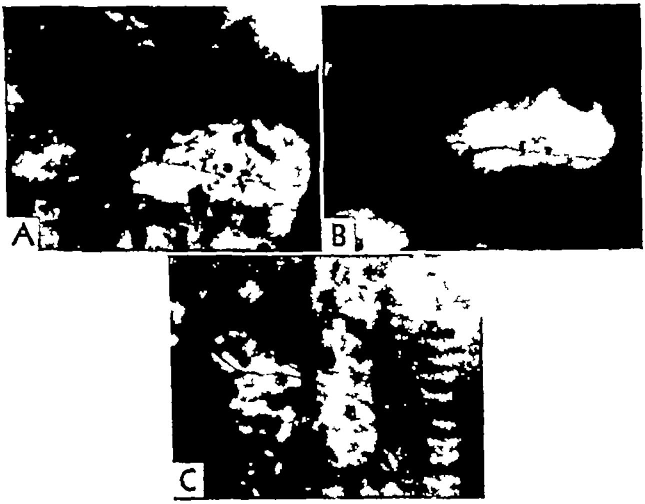

Fig 2

(A)—Medial fibers.

(B) and (C)—Basilar fibers passing through the gallery of Corti (Cajal-De Castro Method—Enl 500X)

4. Some of the spiral fibers of the gallery were found going to the apex, and some to the round window, as demonstrated by Fernandez. In our specimens, compact groups of fibers coming out of the foramina were seen, penetrating radially the gallery of Corti, in whose center they were distributed brushlike. Some of those fibers are directed to the external acoustic cells, whose nervous formations could not be followed. Some branches were found reaching the sustaining cells and the sulcus laminae espiralis. Held[18] attributes the innervation of the internal acoustic cells to these.

5. With the Rio Hortega, in some celloidin sections we

*1* Our findings confirm the majority of those previously reached, mainly those of Kolmer, on the nerve supply of the external acoustic cells The different fibers form the external spiral bundles of the 1st, 2nd, 3rd and 4th orders, progressively decreasing are the continuation of the radial fibers arising from the lamina espiralis, running radially to the gallery of Corti, and considering their particular topographical arrangement, would be better called "spiro-radial fibers"

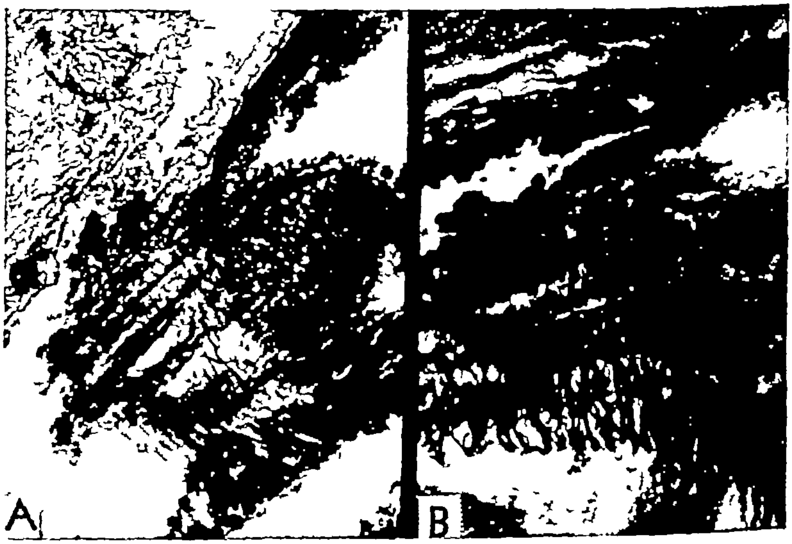

Fig 1

Section of the organ of Corti with the external spiral bundles (Cajal-De Castro Method—Enl 500×)

*2* The fibers that come from the habenula go to the external acoustic cells through the gallery of Corti by the floor or the top, justifying the previous denomination of basilar and medial The basilar fibers reach the acoustic external cells, after passing through the Deiters cells, as well as the medial fibers This is clearly confirmed by Fernandez's topographical distribution of the medial and basilar fibers Both are found along the whole length of the gallery, but the medial fibers are found in greater number in the basal turn, and are gradually replaced by the basilar fibers that are frankly predominant in the apex found pyriform nerve cells of the pseudo-uni-polar type, on the vestibular wall, with one axon directed laterally to the base of attachment of the Reisner ligament and of the tectorial membrane, the other, to the sulcus and base of the limbus espiralis One isolated element of bi-polar type was also found

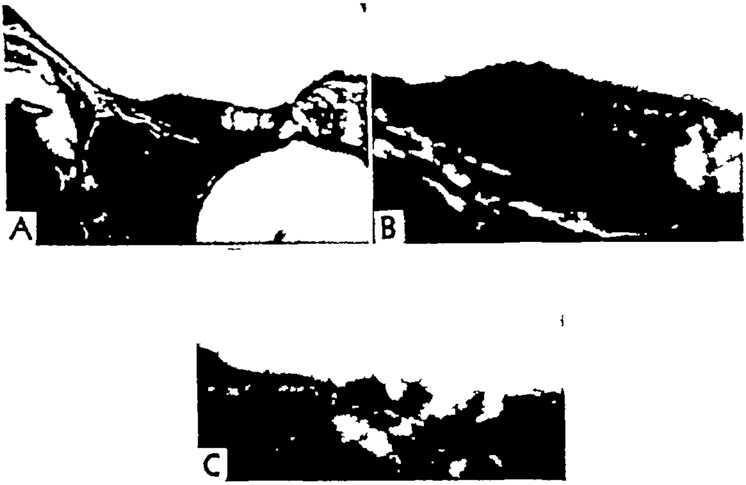

Fig 5

(A)—Vestibular wall of the Limbus Espiralis with pseudo-uni-polar cells (Del Rio Hortega Method—Enl 150X)

(B)—Idem

(C)—Vestibular wall of the Limbus Espiralis with bi-polar cells. (Del Rio Hortega Method—Enl 500X)

*6* Partially confirming and completing Fort's previous description, we assumed in 1956[26] that the cells of the ganglion of Corti are not strictly localized in the Rosenthal's spiral canal There is a gradual diminishing of the cellular elements starting from the spiral canal to the axis of the modiolus The ganglionic cells do not remain in the Rosenthal canal, where they are grouped mainly in the medial and internal portion, but as a matter of fact, are seen along the descending canals of the modiolus, essentially in the proximal portion of each canal, and they should not be considered only similar to the cells at the ganglion of Corti but also as migrated cells, and therfore, as a part of it

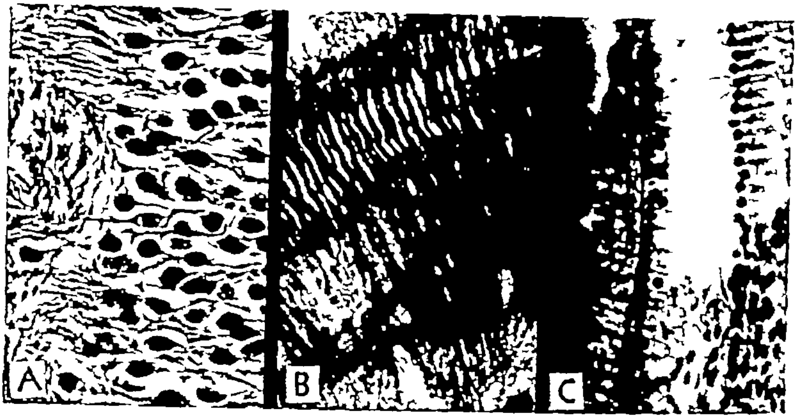

Fig 3

(A)—Spiral ganglion On the left transversally sectioned fibers of the Rasmussen spiral-bundle (Bodian Method—Enl 500\)

(B)—Bony Lamina Espiralis with spiral fibers (Cajal-De Castro Method—Enl 500\)

(C)—Base of internal acoustic cells showing double nerve supply (Bodian Method—Enl 500\)

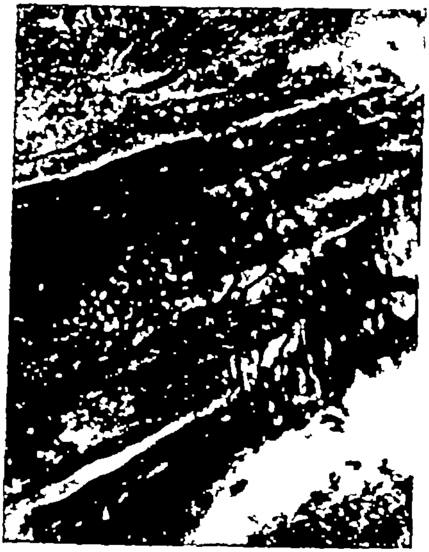

Fig 4

Spiral fibers of the gallery (Cajal-De Castro Method—Enl 500\)

*7* In 1956[2-25] we reported the existence of multi-polar nerve cells in the cochlear branch of the acoustic nerve Probably those cells were an external projection of the primary acoustic nuclei

*8* By the demonstration made, the complication of the cochlear innervation is evident The presence of pseudo unipolar type cells in the vestibular wall of the limbus espiralis, suggests the hypothesis of innervation of the tectorial membrane and, therefore, the possibility of closing a "neuronic arch" between that membrane and the hairs of the internal and external acoustic cells

## SUMMARY

Studying the cochlear innervation of the cat, the author, employing the silver impregnation methods of Cajal De Castro and Rio Hortega, after electrolytical de-calcification, reached the following conclusions

*a* He agrees with Kolmer in the innervation of the external acoustic cells by external spiral bundles of first, second, third, and fourth orders, that by particular topographical disposition would be better called spiro-radial bundles

*b* The Rasmussen bundle is very evident, and some of its fibers turn backwards to the sustaining cells reaching the base of the limbus espiralis

*c* The spiral fibers on the organ of Corti are easily identified

*d* In the vestibular wall of the limbus espiralis were found pseudo-unipolar cells with fibers which were directed to the base of the limbus espiralis and on the other side to the tectorial membrane

*e* The cells of the ganglion of Corti did not remain circumscribed in the Rosenthal canal, but they were also found in the descending canals of the modiolus

*f* In the cochlear branch of the acoustic nerve were found multi-polar cells probably originating in the primary acoustic nuclei

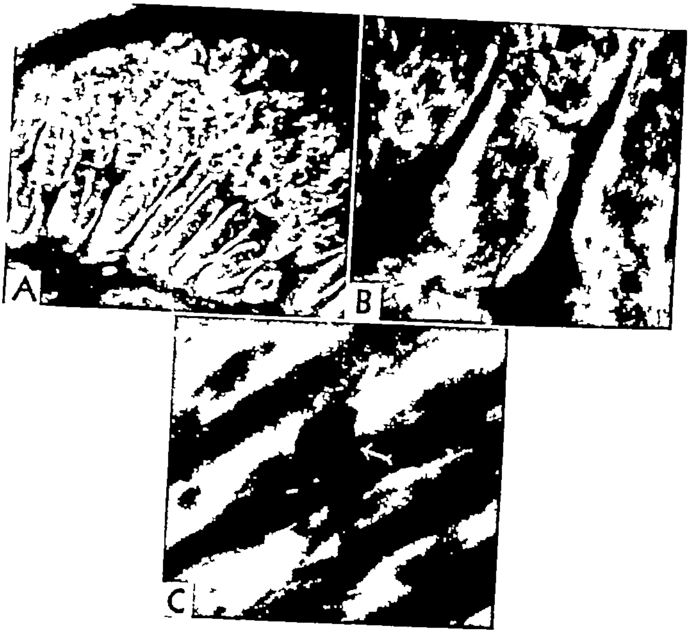

Fig 6

(A)—Rosenthal and descending modiolar canals
(Cajal-De Castro Method—Enl 85X)

(B)—Bi-polar-cells in a descending modiolar canal
(Cajal-De Castro Method—Enl 375X)

(C)—Bi-polar cells in a descending modiolar canal
(Cajal-De Castro Method—Enl 850X)

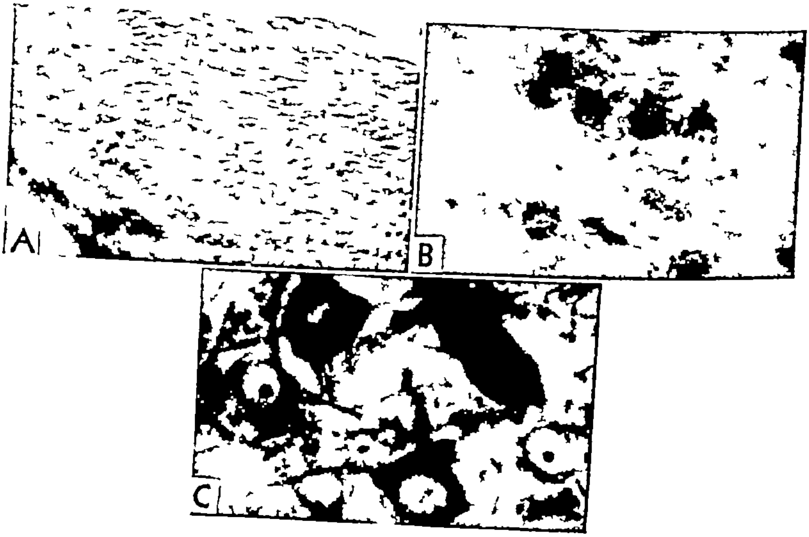

Fig 7

(A)—Acoustic nerve with multipolar cells (Enl 85X)
(B)—Idem —(Enl 375X)
(C)—Iden —(Enl 850X)

(Cajal-De Castro Method)

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# DC POTENTIALS OF THE MEMBRANOUS LABYRINTH

## (Abstract) *

CATHERINE A SMITH,
HALLOWELL DAVIS,
BRUCE H DEATHERAGE,
and
CARL F GESSERT,

Washington University, and Central Institute for the Deaf,

St Louis, Mo

The membranous labyrinth of the internal ear is a closed epithelial tube filled with endolymph and surrounded by perilymph It is divided into compartments by local constrictions and dilations The cochlear duct and the saccule are connected by a short narrow duct The latter is also separated from the utricle by another (indirect) tubule Previous analysis of endolymph has shown it to contain 144 m eq/1 of potassium and 16 m eq/1 of sodium, whereas perilymph shows the opposite potassium-sodium ratio (Smith, Lowry and Wu)

The DC potentials of the cochlear duct, utricle and saccule of the guinea pig were measured by means of a glass pipette-

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*The full paper will be published elsewhere.

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perilymph and surrounding tissues. This DC endocochlear potential is thought[1, 2] to contribute to the generation of the cochlear microphonic and to the associated electrical current flow that is believed to stimulate the nerve endings.[4] The source of the DC potential is unknown. The electrochemical mechanism seems to be rather specific and more closely dependent on oxidative processes than is the familiar negative intracellular polarization.[4] The site of the generation had been tentatively located both in the hair cells and in the stria vascularis. The present experiments were planned in the hope of deciding between hair cells and stria vascularis as the locus, by injuring the inner ear of guinea pigs in ways which could be more or less selective. The experiments actually yielded important additional information concerning the source and significance of both the cochlear microphonic and the negative summating potential.

As an agent to injure hair cells, streptomycin, injected locally into the bulla, was suggested to us by Dr. Harold Schuknecht.[11] He actually made the first three injections in the present series. The procedure directed at the stria vascularis was extensive obstruction of the cochlear vein and some of its collaterals. Kimura and Perlman have described the surgical procedure and the resulting pattern of histological changes in stria vascularis and in the sensory cells.[7] The earliest changes apparently occur in the stria and the spiral ligament.

We did obtain clear differential effects by these two methods. In each case an interval of a few (four to seven) days proved best for obtaining the desired degree of change in electrical activity and in histological appearance.

The electrical responses measured, as indices of the functional state of the organ of Corti, were the cochlear microphonic (CM), the negative summating potential (SP), and the action potential spike (AP). CM is known to depend upon the hair cells. AP is generated by the nerve fibers in the modiolus and gives evidence of the integrity of the overall system of tectorial membrane, hair cell, nerve ending and nerve fiber. SP, like CM, probably originates in hair cells, but the association has not been established clearly. To draw electrode Endolymph was withdrawn in the same pipette for potassium analysis Successive measurements made on the same ear showed the potential of the cochlear duct to be +70 to +80 mv (as described by von Békésy), and that of the utricle, to be not more than +5 mv The saccular potential, measured in other animals, was similar to that of the utricle Endolymph from both utricle and cochlea had a high potassium content similar to that of the previous analysis The high positive potential is, therefore, restricted to the cochlea, whereas the high potassium content appears to be the same throughout the membranous labyrinth

# MODIFICATION OF COCHLEAR POTENTIALS PRODUCED BY STREPTOMYCIN POISONING AND BY EXTENSIVE VENOUS OBSTRUCTION *†‡**

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Washington University,
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## INTRODUCTION

The endolymph in scala media of the guinea pig cochlea shows a positive DC potential of about 80 mv relative to the collaterals was carried out by R K at the University of Chicago The method, the resulting symptoms and the usual histological changes have been described elsewhere The animals were transported to St Louis and tested at intervals ranging from five days to 28 days The most satisfactory degrees of partial injury were found five to eight days postoperatively

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**Assisted by U S Public Health Service Grant B-680

Both the streptomycin and the venous-congestion animals were prepared for final test by our usual methods[13] Dial in urethane 0 5 cc per kilo was given intraperitoneally Rarely, a small supplementary dose was required The treated cochlea was exposed by opening the bulla and two fine, enamel-insulated nichrome-steel wires (25 $\mu$) were introduced through small holes drilled into scala vestibuli and scala tympani respectively 3 to 4 mm from the round window Between these electrodes a fenestra was made through the bony shell of the cochlea to expose the spiral ligament behind the stria vascularis A chlorided silver electrode, wrapped in Ringer-soaked cotton to avoid direct contact with the body fluids, was inserted under the skin at the edge of the wound and, in most experiments, an ear speculum that fitted snugly the output tube of a calibrated sound source[3] was sewed tightly into the external auditory canal

The first four streptomycin animals were simply placed at a standard distance in front of an open loud-speaker and tested qualitatively with 9000 c p s tone bursts, but it was soon found that stronger acoustic stimuli were needed The closed, calibrated system, capable of delivering over 135 db SPL at the test frequency of 7000 c p s , was employed thereafter, and all sound pressure levels readings are corrected to a position just in front of the tympanic membrane

As a standard acoustic stimulus we employed a 7000 c p s tone-burst with a 1 msec rise time and 1 msec fall time The sound level remained constant for 4 (or sometimes 6) msec This interval was long enough to allow easy recognition of SP but too short for echoes in the acoustic system to confuse the pattern The 1 0 msec rise time is the slowest that we found consistent with the good synchronization of nerve impulses that is necessary for a sharp "$N_1$ spike" firm conclusions, therefore, we seek primarily a relation between CM response and the positive DC resting potential of scala media under varying degrees of injury inflicted by the two different methods. Secondly, we seek the relation between depression of electrical activity and any histological changes that can be demonstrated in particular types of cell. Finally, the relationships among the various electric responses are of great interest in their own right, as they indicate possible mechanisms or functional relationships.

## METHODS

Streptomycin sulfate, in doses of 0.1 to 1.0 gm. dissolved in distilled water, was injected into one bulla of each of 26 guinea pigs. The volume of fluid injected was usually about 0.2 cc. The hypodermic needle was at first forced through the wall of the bulla or through the tympanic membrane. It proved more satisfactory, however, to expose the bone of the bulla in a preliminary operation and to drill one hole for the hypodermic needle and another to allow escape of air. Even so, some fluid may have been lost through the Eustachian tube before the drug was entirely absorbed, so that the exact dosages were uncertain.

A time interval of four to seven days between injection and test was convenient and sufficient. Longer intervals increased the chances of complications, such as otitis media and formation of adhesions, and tended to give more injury to the cochlea than was desired.

Practically all 22 of the animals successfully injected and carried to acute experiment, showed signs of unilateral vestibular deficit, such as nystagmus and a head posture with rotation around the long axis, during the first two days of the interval.

At the final experiment the bulla usually contained some mucoid or serous blood-stained fluid, and the mucosa was often thickened and vascularized, but the tympanic membrane was intact and, after the bulla had been swabbed out, the ossicles were usually freely movable.

Surgical obstruction of the cochlear vein and some of its chanical stiffness, and ability to penetrate spiral ligament and structures beneath it without undue injury Details of the construction of the pipette-electrode, its carrier and the associated DC amplifier are given elsewhere[12] Measurements were made on the face of an oscilloscope with the help of an internally illuminated lucite scale A moving-film record of the movements of the oscilloscope spot during insertion and withdrawal of the pipette was made as routine but was actually used only to resolve doubts as to direct scale readings when the changes were unusually complicated or rapid The silver electrodes were freshly chlorided each day

Just before penetration the amplifier was always balanced to give zero reading while the tip of the pipette was immersed in the film of fluid over the spiral ligament A zero reading was also taken again after withdrawal but just before breaking contact This final reading usually agreed within ± 1 mv with the original The pipette was advanced by steps until further advance gave no further increase in DC potential In a few cases the last advance caused a fall in the measured potential, presumably due to penetration of Reissner's membrane Only rarely did we fail to encounter a region of strong positive DC potential on the first attempt Always when the maximum was less than +30 mv and sometimes, as a control, in other experiments a second and even a third penetration was made in a slightly different position or direction Actually, if a potential over 30 mv had been encountered on the first trial no higher potential was found on any later trial, and usually the voltage was the same or a few millivolts less

As control values for DC measurements made in the basal turn by the above method we employed nine initial measurements made in another series of experiments that involved subsequent chemical injections into scala media or scala tympani[5] These experiments overlapped the present series in time

Normal thresholds and input-output curves were determined in a series of 16 experiments that will be described in detail elsewhere The procedures were identical with those of the

Complete input-output functions for cochlear microphonics, action potential and negative summating potential were plotted from measurements made of standing wave patterns on the face of the oscilloscope. The results are expressed as microvolts DC displacement from the resting baseline for the summating potential, as microvolts peak-to-peak for the cochlear microphonic and as microvolts relative to the baseline of the first wave ($N_1$) in the action potential response. CM and SP were both measured as voltage difference between scala vestibuli and scala tympani. AP was recorded between the null point (for CM) on a resistance connected between the scala vestibuli and the scala tympani electrodes and the neck electrode. Adjustment of the variable resistances in the network effectively eliminated CM potentials from the AP trace and vice versa.[13]

With these electrode positions the AP is recorded as the impulses enter the internal auditory meatus, and the spike represents the impulses in *all* fibers that are activated within the first millisecond, regardless of the point of origin in the cochlea. The CM and SP responses and the resting DC polarization, however, are chiefly those generated within one or two mm. of the position of the electrodes. The contribution from distant points falls off rapidly with the distance.[13, 14] The attenuation of CM with distance may be even more rapid than for the DC potentials because of capacitative conduction across the walls of the scala media. The locus of maximal amplitude of displacement of the cochlear partition at 7000 c.p.s. is only slightly apical from the position of the recording electrodes[12, 13] so both CM and SP are recorded efficiently.

After recording the input-output data, we measured the DC potential of the interior of scala media relative to the outer surface of the spiral ligament. The head of the animal had been clamped firmly in a standardized position. A micropipette electrode was now advanced into the scala media by means of a micro-manipulator. Visual control was maintained through a binocular dissecting microscope (20×). Pipettes about 15 $\mu$ outside diameter filled with 0.85 per cent Na Cl solution gave a good compromise among the factors of simplicity of preparation, low enough ohmic resistance, me-generated within one or at the most a very few millimeters The condition of structures three to four mm from the round window is critical, while the condition of cells in the apical turns is irrelevant for the interpretation of our electrical tests except for the action potentials produced by "remote response"[6] The histological findings and also the results of our electrical measurements are summarized in Table I

In the streptomycin series, the mildest degree of injury to the hair cells was a slight pyknosis and shrinkage of the external hair cells in the lower half of the basal turn All but one of these ears, however, showed complete loss of the external hair cells up to, or nearly up to, the position of the recording electrodes The inner hair cells near the electrodes were sometimes present and apparently normal in appearance (see Fig 1) In other cases the nuclei were pyknotic and frequently displaced, and, in the most severely injured ears, the internal hair cells as well as the external hair cells (see Fig 2), and sometimes the supporting structures also, disappeared entirely

The changes in the stria vascularis were much less than those in the organ of Corti The most severe change was a shrinkage of cells with some edema appearing between or behind them (see Fig 3) There was no general cellular degeneration

Changes in the stria and also changes in the hair cells were not necessarily continuously graded but might vary irregularly from section to section Whereas all of the ears in the series showed definite changes in the external hair cells, only six showed recognizable changes in stria vascularis, and only one of these showed injury in the stria that extended throughout the length of the cochlea

In the seven most severely poisoned ears the supporting cells of the organ of Corti had also degenerated Sometimes they still formed a continuous layer (1072, 1078, 1090, 1108) but in others there were bare patches on the basilar membrane (1073, 1089) In the most advanced cases (1071, 1089) replacement of the degenerated supporting cells by squamous epithelium had begun but was not yet complete In the present series except that no fenestra was made in the basal turn, and sometimes a second pair of recording electrodes was placed in the third turn

At the end of the acoustical and electrical tests the animals were perfused with isotonic sodium chloride solution introduced into the aorta After exsanguination the animal was perfused with Heidenhain-Susa solution and the head or the temporal bones prepared for histological study by routine methods The heads of the animals with venous obstruction, studied by C F at the University of Chicago, were sectioned as a whole through both cochleas symmetrically[7] This method of cutting requires careful orientation in the microtome to obtain mid-modiolar sections of both cochleas at once, but allows close immediate comparison between the operated and the opposite normal ear

## RESULTS HISTOLOGICAL

### *Streptomycin*

The injurious effects of streptomycin varied according to the dosage employed, the number of days elapsed following the dosage, the type of tissue, and the distance from the round window The relationships of injury to size of dose and to duration following the injection were not examined closely because it was obvious that only slight correlations exist within the range of dosage represented in our experiments The external hair cells are the most vulnerable cells The supporting structures of the organ of Corti and the internal hair cells are fairly vulnerable, the stria vascularis is affected only slightly, and Reissner's membrane, the basilar membrane, sulcus cells and limbus are very slightly affected, if at all A gradation of effect away from the round window is very clear and seems to establish beyond doubt the route of entrance of the streptomycin, namely through the round window membrane

The ears studied in this series were examined both with relation to the extent lengthwise of the injury and to the severity of injury in the region of the fenestra As noted above, our electrode system is sensitive to CM, SP and DC severely affected ears some degeneration appeared in the limbus also, and the internal and external spiral sulcus cells were lost

In one ear (1125) the cochlear duct was collapsed and Reissner's membrane lay closely against the stria vascularis over the greater part, although not quite all, of its width All of the vestibular membranous labyrinth was likewise collapsed in this ear, even the semicircular canals

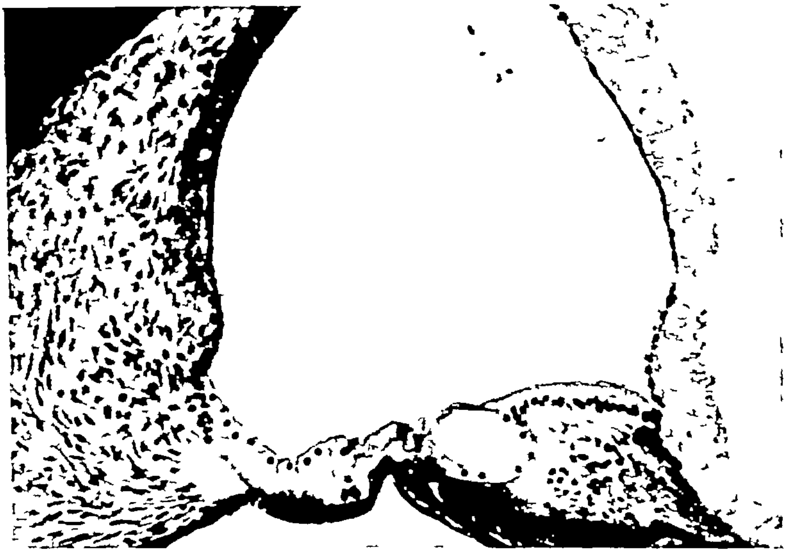

Fig 1. Degeneration of external hair cells in streptomycin poisoning Internal hair cell present in fair condition. Stria vascularis is normal DC potential —81 mv See Fig 10 for input-output curves (Guinea pig 1097)

In some preparations Reissner's membrane bulged somewhat into stria vascularis, either locally or throughout the cochlea, but we attribute this bulging to artifacts of fixation

With the exception of animal 1107 no neural injury was observed, either to the nerve fibers or to the ganglion cells, unless the animal had survived at least six days after the injection After the sixth day the amount and severity of injury to nerve tissues seems to correlate quite directly with

| GUINEA PIG NUMBER | TREATMENT | | | HISTOLOGICAL IN BASAL TURN NEAR ELECTRODES | | | RESTING DC | ELECTRICAL RESPONSES TO 7000 CPS BURSTS | | | | | | | | | GUINEA PIG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | STRIA VASCULARIS | HAIR CELLS INTERNAL | HAIR CELLS EXTERNAL | MV | CM DB - SPL Thresh | CM DB - SPL Break | CM DB - SPL Max | CM µV Max. | SP DB at 8 µV | SP µV 110 db | AP DB Thresh | AP µV at 57 db | AP µV at 110 db | |
| **NORMAL MEDIANS** | | | | | | | N 9 77 | | | | | | | | | | |
| | | | | | | | N 18 | 35 | 76 | 103 | 800 | 63 | 500 | 26 | 100 | 400 | |
| **STREPTOMYCIN** | | | | | | | | FIELD STIMULATION | | | | | | | | | |
| | DAYS | GM. | | | | | | | | | | | | | | | |
| 1071 | 12 | .12 | | 1 Slight local changes | ABSENT in all turns | ABSENT | 5 to 10 | No responses to 9000 cps bursts at about 100 db | | | | | | | | | 1071 |
| 1072 | 12 | .08 | | NORMAL | Mostly ABSENT | ABSENT | 90 to 95 | | | | | | | | | | 1072 |
| 1073 | 7 | 16 | | 1 Moderate local changes | Entire ORGAN of CORTI | ABSENT in all turns | < 4 | | | | | | | | | | 1073 |
| 1078 | 7 | .07 | | 2 Moderate injury | ABSENT | ABSENT | 95 | | | | | | | | | | 1078 |
| 1088 | 8 | .20 | | 1 Very slight changes | ABSENT in all turns | ABSENT | 5 | | | | | | | | | | 1088 |
| | | | | | | | | CLOSED ACOUSTIC SYSTEM | | | | | | | | | |
| 1079 | 7 | 07 | | ▲ NORMAL | Minimal injury | pyknotic and shrunk | 87 | | | 105 | | present | | good response | | | 1079 |
| 1090 | 6 | 06 | | NORMAL | FAIR | ABSENT transition zone | 77 | | very small | | | present | | present | | | 1090 |
| 1096 | 4 | 06 | | NORMAL | ABSENT in all turns | ABSENT | 60 | 113 | | ? | 2 | Not seen at 110 db | | | | | 1096 |
| 1097 | 4 | 10 | | NORMAL | FAIR | ABSENT transition† | 81 | 78 | 99 | 107 | 38 | 78 | 256 | 64 | 0 | 152 | 1097 |
| 1099 | 4 | .04 | Conductive* 7db | Specimen damaged in preparation | | | 89 | 49 | 88 | 106 | 264 | 62 | 260 | 38 | 34 | 256 | 1099 |
| 1101 | 3 | .04 | | NORMAL | FAIR | ABSENT below GOOD above | 79 | 38 | 70 | 95 | 280 | 51 | 320 | 32 | 36 | 138 | 1101 |
| 1107 | 4 | 05 | | 2 Widespread but mild | Shrunk | ABSENT transition | 58 | 64 | 86 | 102 | 60 | 75 | 208 | 69 | 0 | 190 | 1107 |
| 1108 | 4 | .05 | | NORMAL | ABSENT (pyknotic in Turn II) | ABSENT | 73 | 120 | | | 1 | absent at 110 db | | 65 | remote AP | 54 | 1108 |
| 1109 | 4 | .05 | | NORMAL | NORMAL | ABSENT, but fair in Turn II | 72 | 70 | 85 | 105 | 44 | 74 | 160 | 79 | 0 | 60 | 1109 |
| 1110 | 4 | .07 | | NORMAL | NORMAL | Transition | 87 | 50 | ? | 105 | 120 | 59 | 200 | 38 | 54 | 250 | 1110 |
| 1111 | 4 | .06 | | NORMAL | Shrunk | Pyknotic ? | 62 | 43 | 72 | 97 | 210 | 58 | 440 | 38 | 56 | 190 | 1111 |
| 1112 | 4 | .08 | | NORMAL | NORMAL‡ | Transition | 73 | 40 | 68 | 85 | 144 | 50 | 440 | 30 | 114 | 260 | 1112 |
| 1113 | 6 | .07 | | NORMAL | NORMAL | Transition | 93 | 51 | 74 | 110 | 174 | 58 | 432 | 45 | 36 | 268 | 1113 |
| 1114 | 5 | .07 | | NORMAL | FAIR | ABSENT transition above | 88 | 44 | 75 | 95 | 268 | 48 | 500 | 34 | 60 | 240 | 1114 |
| 1123 | 6 | 10 | Otitis Media | NORMAL | GOOD | ABSENT | 86 | Very small responses ; also conductive loss | | | | | | | | | 1123 |
| 1124 | 6 | 13 | | NORMAL | Slightly shrunk | ABSENT transition nearby | 78 | 71 | 85 | 107 | 65 | 79 | 180 | 79 | C | 114 | 1124 |
| 1125 | 6 | 20 | | 1 NORMAL | ABSENT in all turns | ABSENT | 71 | No responses of any kind at 130 db | | | | | | | | | 1125 |
| **VENOUS OBSTRUCTION** | | | | | | | DB re 77 µV MV | | | | | | | | | | |
| 1103 | 7 | | | 4 Severe DEGENERATION | NORMAL | Severe DEGENERATION | 6.8 36 | 65 | no | 107 | 12 | 76 | 64 | 47 | 24 | 240 | 1103 |
| 1104 | 8 | | Otitis Media 15 db | 3 Moderate DEGEN. | NORMAL | Mild Degeneration | 3.2 53 | 71 | 85 | 95 | 18 | 69 | 100 | 66 | 0 | 150 | 1104 |
| 1115 | 28 | | | 3 Partial ATROPHY | NORMAL | NORMAL | 0.8 70 | 35 | 70 | 87 | 340 | 55 | 540 | 22 | 144 | 400 | 1115 |
| 1116 | 6 | | | 4 Transition to Degenerate | NORMAL | NORMAL | 5.3 42 | 36 | 72 | 95 | 340 | 62 | 250 | 53 | 16 | 186 | 1116 |
| 1117 | 26 | | | NORMAL | NORMAL | NORMAL | 0.8 70 | 28 | 71 | 98 | 780 | 53 | 420 | 16 | 118 | 540 | 1117 |
| 1118 | 22 | | Otitis Media* 15 db | NORMAL | NORMAL | NORMAL | -1.1 68 | 33 | 7 | 105 | 640 | 60 | 000 | 31 | 70 | 600 | 1118 |
| 1119 | 8 | | | 1 Worse above and below | NORMAL | NORMAL | 6.6 36 | 42 | 76 | 101 | 360 | 68 | 208 | 40 | 56 | 380 | 1119 |
| 1120 | 5 | | | [illegible] ATROPHY NECROSIS | NORMAL | Very few remain | 14.2 15 | 13 | not | seen | < 3 | no | 0 | 105 | remote AP | 6 | 1120 |
| 1121 | [illegible] | | | 5 DEGEN 1mm below | NORMAL | NORMAL | 13.1 17 | 51 | 71 | 97 | 88 | 78 | 134 | 66 | 0 | 112 | 1121 |
| 1126 | 15 | | | 31 Spotty DEGENERATION | NORMAL | NORMAL | 1.4 65 | 32 | 72 | 96 | 660 | 70 | 840 | 20 | 140 | 520 | 1126 |

TABLE I

Δ The numbers in this column indicate degrees of abnormality of stria vascularis No entry = normal 5 = complete degeneration Details in text

* This correction has been applied in deriving the values of electrical data that are printed in small figures

o Reissner's membrane has collapsed over parts of the stria vascularis but elsewhere it is normal

† In this and other transition zones the external hair cells are absent below and present but not entirely normal above the electrodes

‡ The organ of Corti has collapsed in this preparation but this is probably an artifact

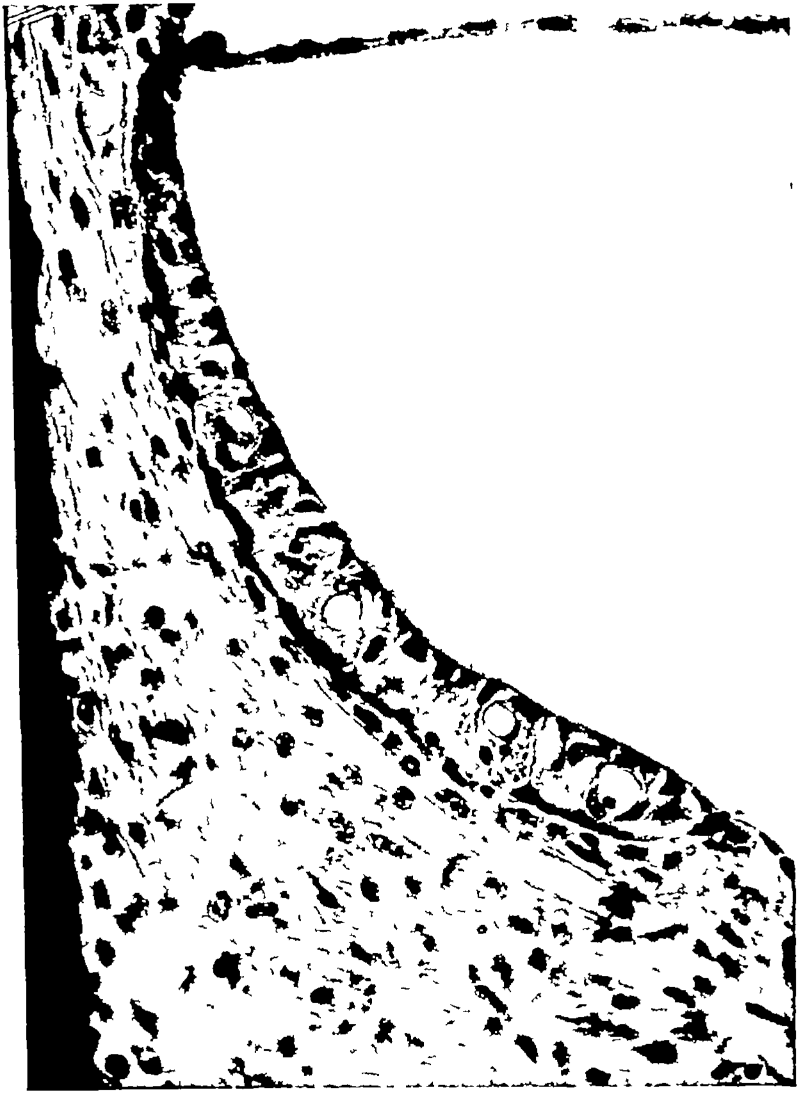

Fig 3 Mild injury of stria vascularis in streptomycin poisoning the most severe in the entire series DC potential +58 mv (Guinea pig 1107)

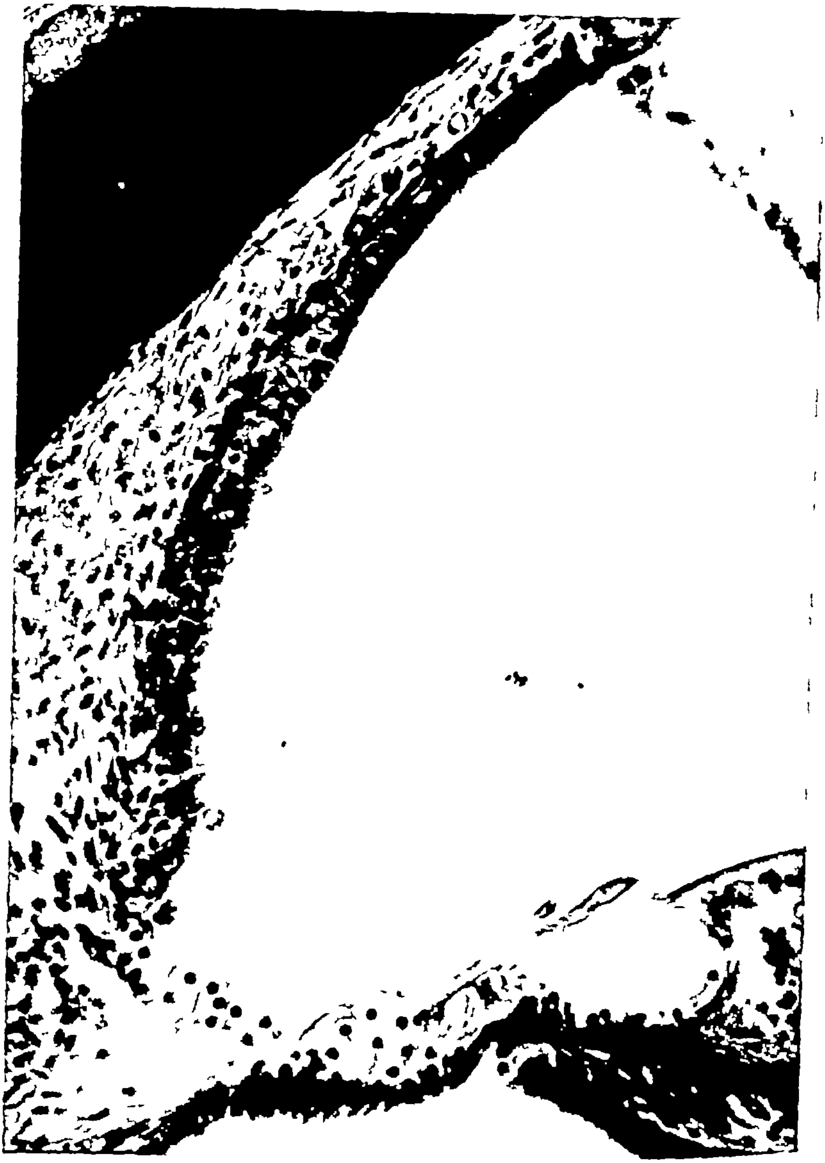

Fig 2 Degeneration of both external and internal hair cells in streptomycin poisoning Supporting cells present but abnormal Stria vascularis is normal Folding of basilar membrane is a fixation artifact DC potential +73 mv See Fig 12 for input-output curves (Guinea pig 1108)

3 Atrophy of some cells but not more than 50 per cent

4 More than 50 per cent of cells atrophic, usually accompanied by necrosis

5 Almost complete necrosis (Complete necrosis of stria vascularis was not seen in this series)

Grades 1 and 2 are characteristic of the streptomycin series The changes occurred usually near Reissner's membrane or the spiral prominence where a few cells might be degenerated or sloughed off These degrees of injury appear compatible with normal function Grades 4 and 5 were seen only in the venous obstruction animals, in six of which the stria vascularis was injured more severely than in any streptomycin animal With such injuries normal function would be very improbable or impossible The atrophy, when present, tended to be localized near the round window while the necrosis was usually quite extensive In Table I the numbers indicate the degree of injury at the position of the electrodes

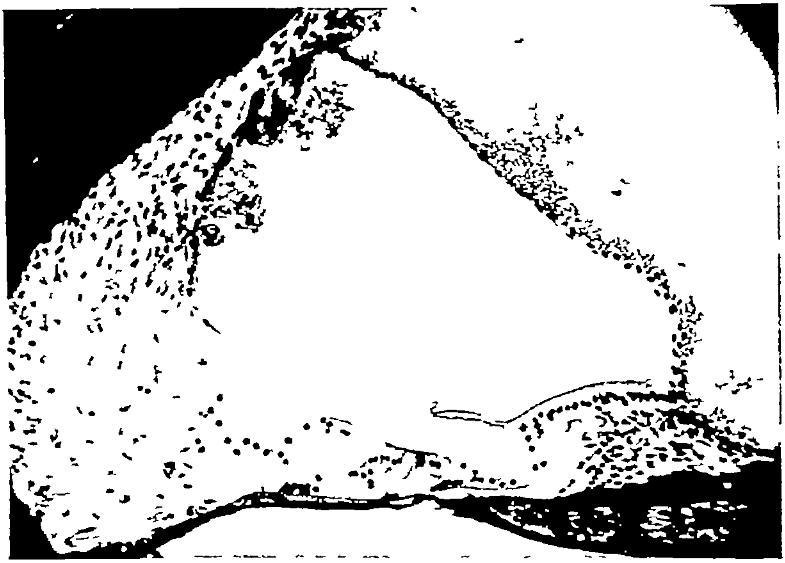

Fig 4 Degeneration of stria vascularis Grade 5 with normal hair cells and other structures of the organ of Corti DC potential +17 mv See Fig 9 for input-output curves (Guinea pig 1121)

the amount of injury to the hair cells It seems reasonable to suppose, therefore, that the injury to nerve tissues is not primary but is secondary to degeneration of the hair cells

## *Extensive Venous Obstruction*

Satisfactory histological preparations were made of the cochleas with extensive chronic venous obstruction In general the effects were more severe in the animals studied within eight days following the operation Recovery apparently occurred after establishment of collateral circulation unless, as in some cases not studied electrically, part of the cochlea degenerated completely

The histological changes were always most severe in the immediate neighborhood of the round window The apical turns appeared quite normal and, just as with the streptomycin poisoning, the electrodes in several cases were placed in or very close to a zone of rapid transition from "nearly normal" to "clearly abnormal" tissues Unfortunately, this gradation of injury makes inferences as to the relation of electrical potentials to particular structures less secure than we had hoped

The tissue most severely affected by venous obstruction was the stria vascularis Next in order came external hair cells, the spiral ligament, and the supporting structures of the organ of Corti Slight hemorrhages into the perilymphatic spaces were frequent Other tissues were not affected

The obvious changes in the stria vascularis were *a* atrophy of the epithelium from the normal pseudostratified columnar to a simple cuboidal epithelium, *b* thrombosis or absence of the blood vessels, and *c* sometimes a detachment of whole cells or extrusion of pigment granules (see Figs 4, 5)

In Table I the degree of injury to the stria vascularis is coded as follows

*1* Some slight changes in a few cells

*2* Most cells shrunken with some edema between or behind them, but no general cellular degeneration

With venous obstruction the changes in the hair cells were pyknosis or total absence of nuclei In the spiral ligament nuclei were sometimes missing, and scattered macrophages appeared All of these changes and their distribution are similar to those already described elsewhere

In one ear (1116) with normal hair cells and only local degeneration of stria vascularis near the round window, Reissner's membrane was partially collapsed In another, with normal hair cells and a local region of mild degeneration of the stria, Reissner's membrane was torn from round window to the third turn The electrical responses of this cochlea were emphatically normal (1117) and the damage is interpreted as an artifact There were no other suggestions of abnormalities of hydrostatic pressure

The cochlear aqueduct was not normally entered during the operation producing obstruction of the cochlear vein, but histological examination showed that it had been blocked in five experiments (1103, 1104, 1115, 1118 and 1119) In none of these, however, was there any abnormality of structure or electrical response that could be attributed to the blockage Animals 1115 and 1118, with survivals of four and three weeks, showed blockage of the aqueduct with new bone formation but they also had normal histology and electric responses This is clear evidence that the cochlear aqueduct is "dispensable" in the guinea pig

## RESULTS AND INFERENCES ELECTRICAL

### *Endocochlear DC Potential*

The endocochlear DC potential of nine normal controls ranged from +64 to +90 mv The mean, the median and the mode of this group were all +77 mv The distribution was normal in form as far as one can tell with such a small sample

The ears injected with streptomycin divided clearly into two groups In three animals (1071, 1073 and 1089) the endocochlear potential was 10 mv or less From none of these three ears was any electrical response (CM, SP or AP) obtained with 9000 c p s tone bursts at 65 db above the

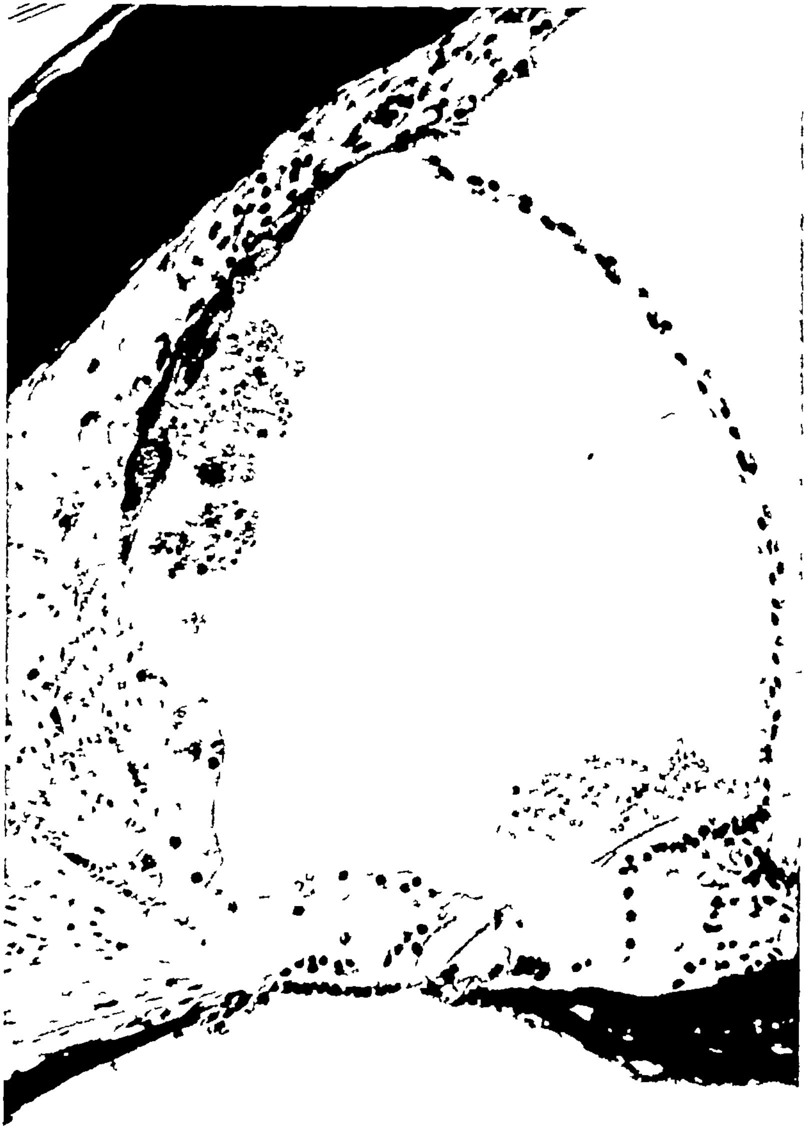

Fig 5 Atrophy and necrosis of stria vascularis Grade 5 Internal hair cells present External hair cells mostly absent DC potential +15 mv (Guinea pig 1120)

the lowest DC potential in the streptomycin series (+58 mv) showed the most definite and widespread injury in the stria vascularis (see Fig 3) The injury was not severe, however, in comparison with those produced by venous congestion

The other ears showed normal DC potentials with varying degrees of elevation of their CM "threshold"

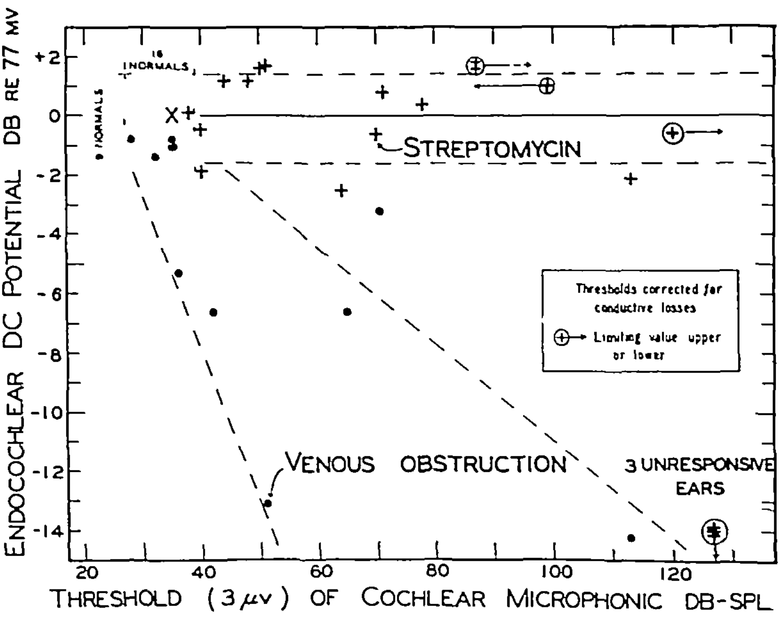

Fig 6 Distribution of endocochlear potentials with respect to cochlear microphonics. The large X indicates the median values of two groups of normal ears

Obviously, the DC potential can exist quite independently of the external hair cells and the CM response, but a normal or nearly normal stria vascularis is always present

The ten ears in which venous obstruction was produced divide into three groups with respect to their DC potentials Four were within normal limits, although all ten were below the control median Two (1120 and 1121) were greatly depressed, while the other four showed intermediate, moderately depressed potentials The four best ears had all been obnormal threshold. In all three the hair cells were absent in all turns, and the entire organ of Corti showed severe degeneration in the first turn. In 1073 and 1089 there were bare patches of basilar membrane, and in 1071 a very thin squamous epithelium had almost, but not entirely, replaced it. The stria vascularis, however, showed only the mildest degree of abnormality in patches here and there.

These three ears do not help to identify the generator of the DC potential. The potential may have been low because the generator in the organ of Corti was destroyed, or else because an intact generator in stria vascularis was short-circuited by a low-resistance pathway through denuded or incompletely covered basilar membrane. The basilar membrane and the mesothelial cells on its tympanic surface alone do not seriously obstruct the movement of ions.[14] The electrical barrier is the organ of Corti, the cells of Claudius and the sulcus cells.[12]

The other 19 streptomycin-treated ears are more decisive. All showed normal or nearly normal endocochlear DC potentials. Only three, at +58, +60 and +62 mv., lay below +64 mv., the lowest of our nine controls. Four showed potentials higher than +90 mv., the highest control. The entire distribution is shown graphically in Fig. 6. Here the abscissa is the "threshold" of the cochlear microphonic response. We shall see below that the voltage of the microphonic correlates very closely with the degree of injury to the external hair cells.

In 1108 a questionable CM response was seen, but only at 129 db SPL. All hair cells, external and internal, were absent in Turn I, but DC was +73 mv. Stria vascularis was normal. In 1096 a doubtful CM appeared at 113 db SPL. All hair cells were missing in all turns but the DC was +60 mv. Again stria vascularis was normal. The two ears (1072, 1078) that showed the highest DC potentials, +92 and +95 mv., gave no CM, SP or AP at 100 db SPL (9000 c.p.s. burst). The hair cells were nearly or completely absent in Turn I in both ears. Stria vascularis was entirely normal in 1072 and nearly so in 1078. On the other hand the ear (1107) with

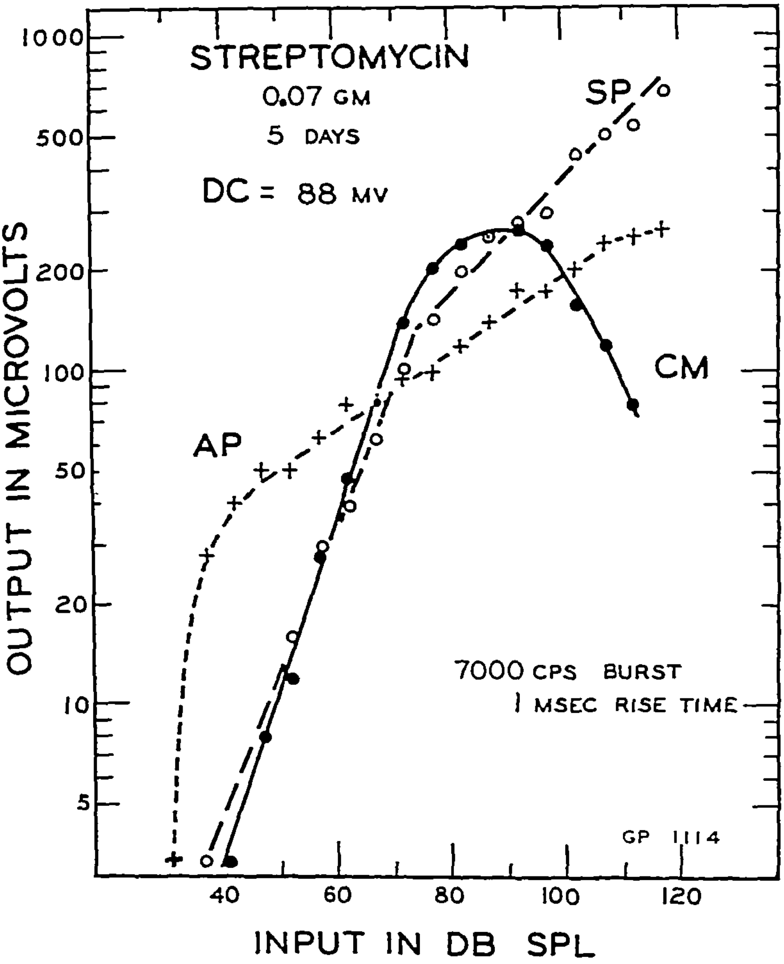

Fig 8 Normal AP and nearly normal SP input-output curves with slightly depressed CM from an ear poisoned with streptomycin. DC potential is normal

as well as the endocochlear DC potential were very greatly reduced The latter was only +15 mv The internal hair cells were apparently normal The external hair cells were missing, and the stria was atrophic above and necrotic below the position of the electrodes

The other depressed ear (1121) showed nearly normal hair cells, but a severe degeneration of stria vascularis from the

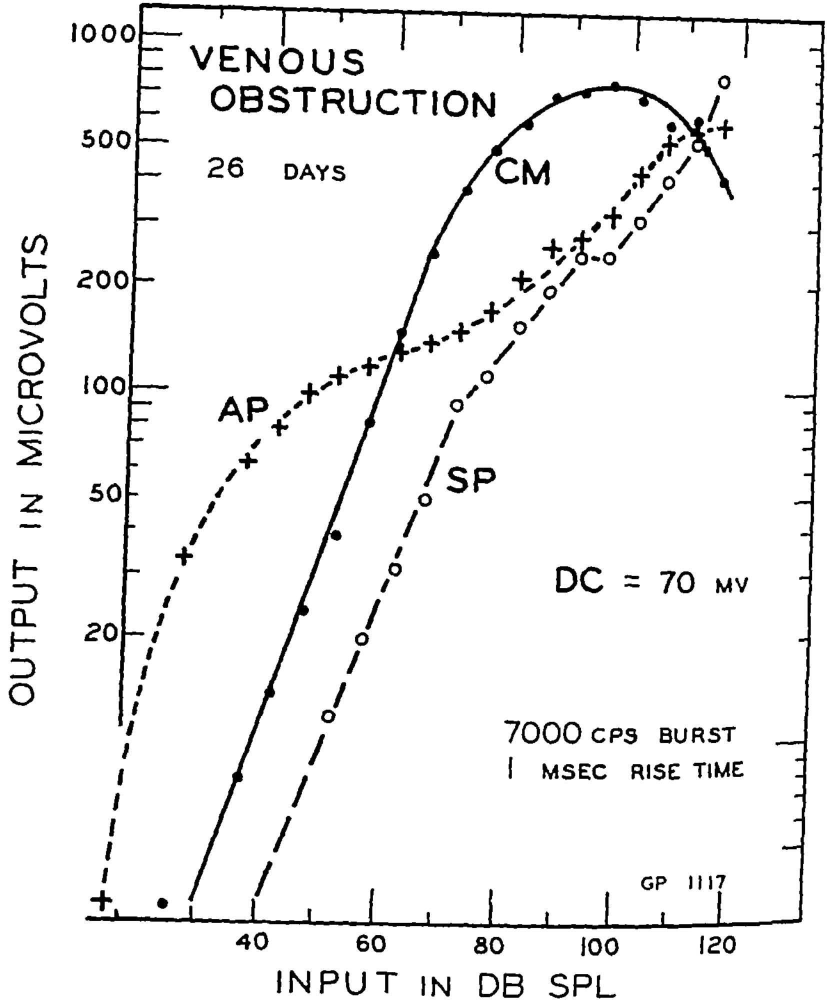

Fig 7 In this and subsequent graphs of input-output functions the threshold response plotted at $3\mu v$ has sometimes been interpolated or extrapolated In Table I however the threshold is the threshold of recognition of the response on the oscilloscope and sometimes differs slightly from the plotted value Stimulus 7000 c p s tone burst with 1 msec rise time Electrodes in the basal turn in all cases. In Guinea pig 1117 with venous obstruction the input-output relations were substantially normal

structed at least 15 days previously, and in general their electrical responses were all within normal limits except for a reduced CM maximum voltage in one case The histological findings were also normal

In one of the depressed ears (1120) the electrical responses show that the DC potential may be practically normal with no hair cells present but good stria vascularis, and that even with normal hair cells it may be very low if the stria vascularis is severely injured *All of our experiments are consistent with the interpretation that the endocochlear DC potential is generated by the stria vascularis and not by the hair cells*

*The Cochlear Microphonic*

The form of the input-output function is very stable The output is linearly proportional to the instantaneous acoustic pressure at low and moderate levels, but goes through a maximum at a high level (Fig 7 illustrates a normal CM response curve ) The sound pressure levels at which the first deviation from linearity appears and at which the maximum is reached depend on the acoustic frequency of the stimulus and on the position of the recording electrodes For our control series the median values were 76 and 103 db respectively These levels are so stable, even when the output voltage is greatly depreseed by streptomycin or by venous obstruction, that we were able to infer from elevated values in three cases (1099, 1104 and 1118) that there were conductive losses of 7, 15 and 15 db respectively Otitis media with adhesions had been noted at operation and/or was demonstrated by microscopic examination in each case (In Table I it is the corrected values that are entered )

From the stability of the shape of the CM response curve and of the sound pressure level that elicits maximal response, even when the hair cells are injured and the CM output voltage is reduced, we infer that the shape of the upper part of the CM response curve is mechanically determined by structures and forces outside the hair cells[4]

A third convenient index of CM response is the threshold of visibility of the CM on the oscilloscope This value agrees very well with the sound pressure level that yields a 3 $\mu$v peak-to-peak response as determined by extrapolation from measurements at higher level

The final index of CM response is the maximum peak-to-peak output voltage Our median control value is 800 $\mu$v

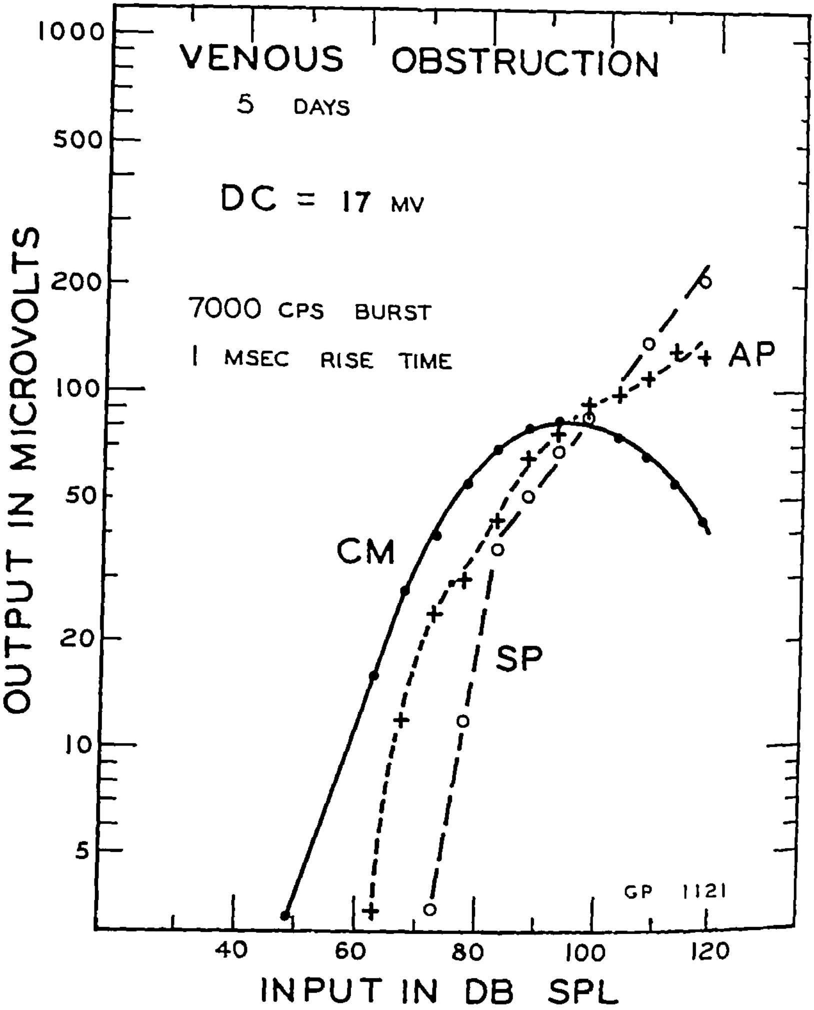

Fig 9 Moderately depressed input-output curves with very low DC endolymphatic potential in an ear with venous obstruction The degenerated stria vascularis and intact hair cells are shown in Fig 4

round window to within 1 mm of the electrodes (see Fig 4) The latter were located in a transition zone between severely and mildly degenerated stria The electrical responses (see Fig 9) were definitely but only moderately depressed The DC potential, however, was only +17 mv

Ear 1121 with venous obstruction, and ear 1096 in the streptomycin series, form a perfect contrasting pair They

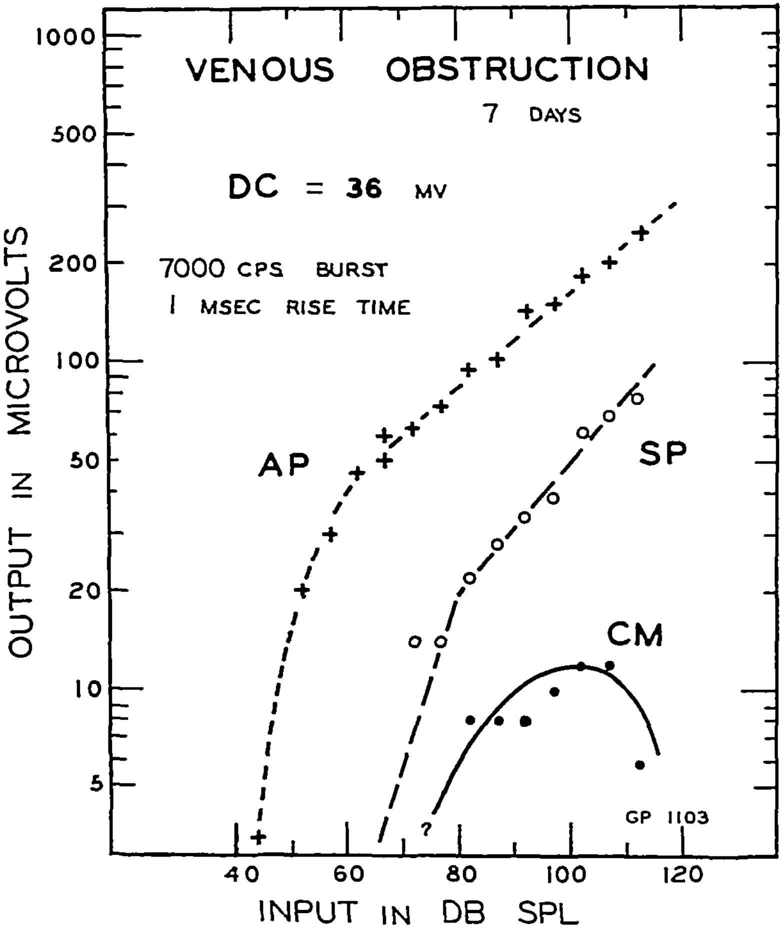

Fig 11 Input-output curves from an ear with venous obstruction This ear showed the strongest AP response relative to CM in the entire series. DC potential is depressed

series offers many examples of this correlation, and the venous obstruction series adds three more

In every case in which no external hair cells remained (within three millimeters of the electrodes) the maximum CM was not more than 3 $\mu$v In these cases when a trace of CM remained the threshold was elevated by at least 75 db In other ears, which yielded depressed CM responses five or ten per cent of the normal maximum, and with thresholds

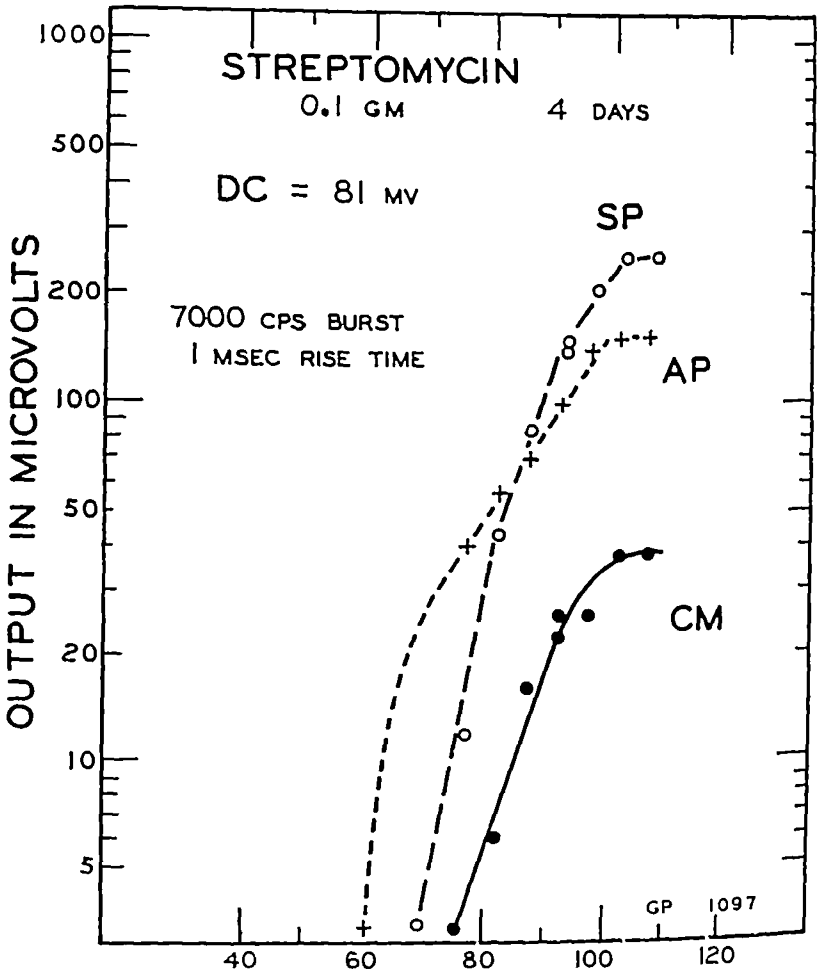

Fig 10 Depressed responses particularly CM in the presence of normal DC endolymphatic potential following treatment with streptomycin The degenerated external hair cells of this ear are shown in Fig 1

The values for all four indices for the individual ears and for the medians of the control series are given in Table I, and full curves are presented in Figs 7 to 12 for six ears that represent various degrees of depression of cochlear microphonic, summating potential and action potential

The cochlear microphonic has for many years been attributed to the hair cells[1] This interpretation is confirmed without exception in the present experiments if we confine the statement to the *external hair cells* The streptomycin en hair cell with a pyknotic nucleus may generate a significant, though perhaps subnormal, cochlear microphonic

The internal hair cells, however, were normal or very nearly normal in appearance in all cases of venous obstruction In six cases of streptomycin poisoning they were at least in fair condition, perhaps a little pyknotic or shrunken We can say with confidence that the contribution of the internal hair cells to the CM response is at most quite small compared to that of the external hair cells In several cases we cannot tell whether the small residue of CM (five to ten per cent of normal maximum) came from good internal hair cells that were present near the electrode, or from scattered or shrunken external hair cells that were found a millimeter or so away Number 1120 shows that internal hair cells can at least appear normal under the microscope without yielding a CM response, but this case is complicated by abnormal stria and low DC potential

In summary *Our evidence strongly supports the hypothesis that the external hair cells are the anatomical locus of the generation of the cochlear microphonic, and that the internal hair cells contribute little or nothing to this response*

### *The Summating Potential*

SP is a DC response to acoustic stimulation The input-output curve of the summating potential is much more variable from animal to animal, and under different conditions in the same animal, than is the response curve of the cochlear microphonic SP is observed as a displacement of the baseline of the CM in the direction indicating that scala vestibuli has become more negative relative to scala tympani (cf 9) A full description of the summating potential is in preparation for publication elsewhere In general, however, *1* the threshold of detection of SP is 20 to 30 db above that of CM, *2* the first segment of the response curve is linear, like CM, *3* the upper segment at sound pressure levels above 100 db SPL is relatively stable and continues to rise up to destructive sound pressure levels (see Figs 7 and 8) The SP response is likely to be larger and more stable in the presence

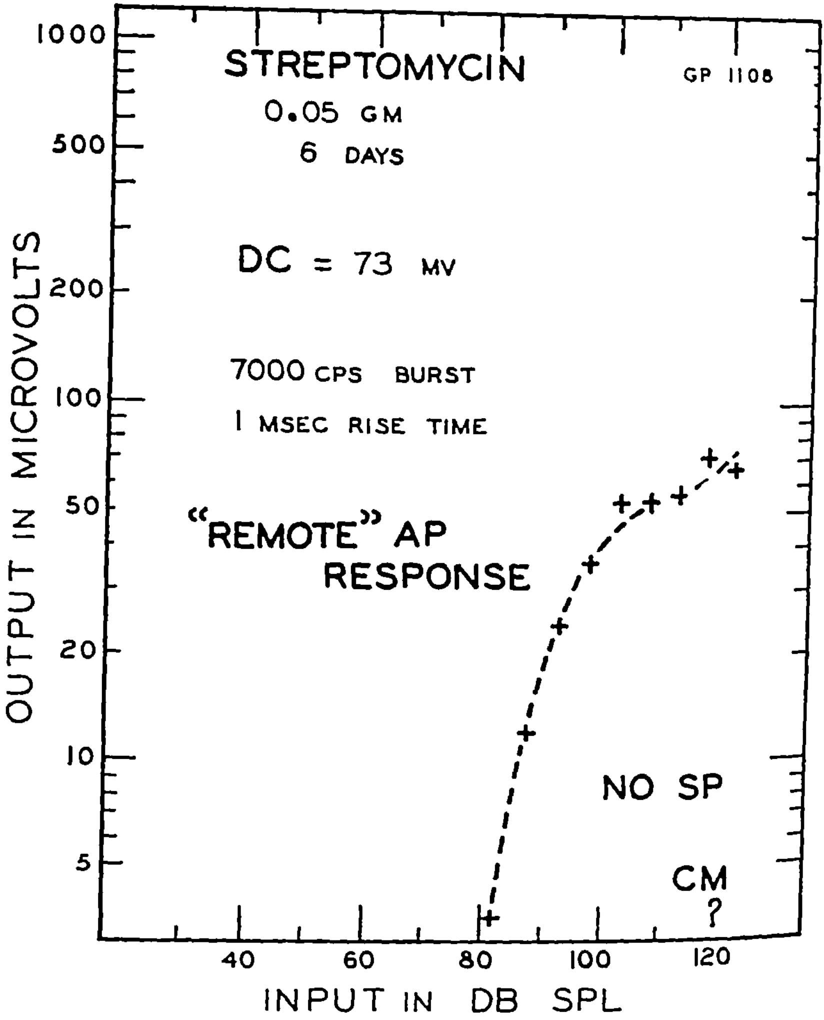

Fig 12 Following treatment with streptomycin the first turn of this ear showed no local responses A typical input-output curve was obtained for the remote component alone of the AP response The degenerated hair cells in the basal turn are shown in Fig 2 Hair cells were still present in the apical turns. The DC potential was normal

elevated 30 db or more, either the external hair cells were badly shrunken and pyknotic in the first turn or, more usually, the electrodes had been placed squarely in the transition zone between absent external hair cells toward the round window and some external hair cells, perhaps with pyknotic nuclei, present within one millimeter apically Apparently a shrunk-spite of the rather small number of cases, the anatomical source of the negative summating potential is the internal hair cells A small contribution from some external hair cells is also possible.

*Action Potentials*

The normal form and the expected variations in the input-output curve for the $N_1$ action potential spike in response to a 7000 c p s tone burst will be given more fully elsewhere Fig 7 (1117) shows a fair sample of such a curve, however It rises abruptly from a true threshold response, and it continues to rise, but with varying slope, up to injurious sound pressure levels Two "humps" in the curve are quite typical, one with its maximum near 60 db SPL, the other about 100 to 110 db SPL Convenient arbitrary indices of the AP curve are *1* the SPL at threshold, *2* the microvolt response at 57 db SPL and the microvolt response at 110 db SPL

The selection of these two arbitrary levels is dictated in large part by our impression that the AP response curve is made up of three components, each generated by a separate "population" of neurons and stimulated by a different group of sensory cells (cf 11) The low-intensity population, centering at 57 db SPL, seems to depend quite closely on the presence of a good CM response On the other hand, expt 1097 (see Fig 10) is an excellent example of absence of the low-intensity (CM) population but a nearly normal high-intensity population The CM response in this case is very small (Note that the scale is logarithmic) On the other hand the SP response, which is a less sensitive mechanism, is nearly normal

We believe that the neurons of the low-level population are those activated by the external hair cells and that the CM is part of the mechanism that activates them We further believe that the high-level population centering at 100 to 110 db SPL is the group of neurons activated by the internal hair cells and that SP is part of the mechanism that activates them This hypothesis is specifically formulated for the response of the basal turn of the cochlea to a 7000 c p s tone burst with a 1 msec rise time, but we believe that in general of slight injury, such as mild anoxia, holes in the cochlea, etc, than in fully normal ears

For the present analysis only two indices proved simple and stable enough to be useful the first is the "8 μv threshold," i e the sound pressure level that just elicits an 8 μv SP response, and the SP voltage at the arbitrary level of 110 db SPL The values are given in Table I

Under an injury by either streptomycin or venous obstruction that reduces CM voltage or raises its threshold the SP remains at or near normal values, and sometimes (*e g* 1103, 1097) it may remain fairly prominent when the CM is greatly reduced or almost abolished The SP follows CM in general, however, in its relation to injury to the organ of Corti and does not, in the crucial experiments (1096 and 1121), follow the resting endocochlear DC potential in its relation to the stria vascularis It appears clearly to be a response of the organ of Corti to acoustic stimulation

The class of cell in which pathological changes correlate most closely with depression of SP is the internal hair cell This cell is rather more resistant to injury by any agent we have used than the external hair cell SP is absent in all eight cases in which the internal hair cells are absent in Turn I It is present in all cases but one in which they are present, even when they are described as "fair", "shrunk" or "pyknotic nuclei" The quantitative correlation is good in all but three cases, all of which are in the venous obstruction series One of these (1104) was complicated by a conductive hearing loss so that SP voltage at 110 db could not be determined, 1103 (see Fig 11) showed a small SP, and 1120 showed no SP both in the presence of "normal" internal hair cells In 1103 we must postulate either partial anoxia of the animal during the test or covert injury to the internal hair cells In 1120 (see Fig 5) there is indirect evidence of poor circulation in the distended capillaries found in stria vascularis and in unusually extensive "hemorrhage and precipitate" in the perilymphatic spaces

We believe that in spite of these two partial exceptions that require additional, although plausible assumptions, and in ound window, causes degeneration first of external, then of nternal hair cells, and then of supporting cells of the organ f Corti The stria vascularis is very little affected

*2* The persistence of a normal positive DC endocochlear otential after streptomycin has destroyed the hair cells liminates the hair cells as possible generators of the DC otential (It is not reasonable to attribute a DC potential f *+70 mv or more* in scala media in the first turn to generators located in higher turns The "space constant" established by Misrahy[3] for the scala media is too small in other words, the basilar membrane and organ of Corti are too leaky electrically to distribute the DC potential very far along the cochlea away from the region of its generation )

*3* Extensive venous congestion, both acute and chronic, affects stria vascularis more quickly and profoundly than the hair cells

*4* The systematic depression of the positive DC endocochlear potential by venous congestion supports the theory that the stria vascularis is the generator of this potential

*5* The effect of venous congestion on the cochlear microphonic, on the summating potential and on the action potentials is variable, depending on the exact degree of injury to various tissues in the neighborhood of the electrodes, particularly the hair cells

*6* The DC endocochlear potential is not necessary for the generation of CM (It may, however, serve to make the CM response larger or more sensitive )

*7* CM is probably the immediate stimulus to nerve fibers near threshold, but a fairly good AP response is still possible with a very small CM

*8* SP is always present when the AP response is greater than that which can be attributed to the "remote response" of the apical region SP, as well as CM, is probably an effective stimulus to nerve fibers

*9* Internal hair cells that appear normal under ordinary microscopy may not yield a significant CM response the external hair cell and CM are a sensitive low-level mechanism, and the internal hair cells and SP are a less sensitive and more rugged high-level mechanism This hypothesis incidentally explains how the AP output curve can continue to rise at levels above 105 db SPL, at which the CM output curve is falling

The final rise in the AP curve is assisted by the "remote response" described earlier by some of us[6] A tone burst at levels above about 80 db SPL evokes not only local movements of the cochlear partition and corresponding CM and SP responses, but also a new mechanical wave that in time-course and amplitude corresponds to the envelope of the tone burst This is a mechanical detector (demodulator) action The new mechanical wave activates the apical part of the cochlea that is appropriate to its long wave length, which is determined by the rise-time of the burst The resulting "remote" action potentials from more apical regions add with the action potentials of the neurons that innervate the first turn They constitute a third, very-high-level population

Fig 12 (1108) in which all hair cells, both inner and outer, were absent in Turn I, but in which pyknotic inner and outer hair cells were both present in Turn II, is a beautiful example of a pure "remote" AP response curve Notice that no SP and only a doubtful 3 $\mu$v CM could be detected in Turn I

An inference from experiment 1108 is that the detector action that initiates the remote wave does not involve the hair cells It must be a prior mechanical event, like the process that is responsible for the maximum in the CM response curve

## CONCLUSIONS

The foregoing observations on cochleas poisoned with streptomycin or depressed by extensive venous congestion, taken in conjunction with our previous knowledge of the electrical potentials of the ear, serve to establish or to support strongly the following conclusions and interpretations

*1* Streptomycin, when it has been absorbed by way of the

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# ACETYLCHOLINESTERASE AND THE OLIVO-COCHLEAR TRACT OF RASMUSSEN

## (Abstract) *

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Henry Ford Hospital,

Detroit, Mich

A high concentration of acetylcholinesterase is found on the nerve fibers and endings of all four rows of hair cells in the cat cochlea When the olivo-cochlear tract of Rasmussen is cut in the brain stem, the quantity of acetylcholinesterase diminshes greatly, and after several weeks disappears almost entirely

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*The full paper will be published elsewhere

*10* The negative summating potential is, in general, more resistant to depression by streptomycin or by venous congestion than either CM or AP

*11* Injury by either streptomycin or venous congestion tends to make the SP response function more regular and even to increase the negative SP response above normal (This may be due to elimination of a very vulnerable positive SP response A strong positive SP appeared temporarily during a single experiment on acute venous congestion )

*12* The negative SP can still be present in the absence of external hair cells SP has not been seen when internal hair cells are also absent This does not exclude the possibility that external hair cells, when present, may *also* generate SP, but the external hair cells probably produce all or nearly all of CM, and the internal hair cells probably produce all or nearly all of negative SP (The external hair cells are the most probable source of *positive SP,* because both positive SP and the external hair cells are highly vulnerable to injury )

*13* The position of the maximum CM response on the intensity axis remains fixed in spite of injury by either streptomycin or by venous congestion This strongly indicates that the maximum in the CM response, and probably also "breaks" in the SP input-output curves, are almost certainly controlled by physical (acoustical or mechanical) factors prior to the bending of hairs of the sensory cells

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## SESSION C

May 16, 1957

# APPLICATIONS AND LIMITATIONS OF AUDITORY TESTS IN SURGERY OF THE STAPES

(Abstract)

SAMUEL ROSEN,
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New York, N Y,

and

MOE BERGMAN,
Hunter College,
New York, N Y

The relative sensitivity thresholds of hearing by air conduction and bone conduction, the so-called air-bone gap, seem to be the most meaningful audiologic criterion for the selection of cases for stapes surgery In general, the amount of hearing loss does not enter critically into the decision to operate, if there is a significant air-bone gap Other audiologic measures, such as the discrimination score and tests for recruitment give useful information but, in the presence of a significant air-bone gap do not substantially influence the decision for or against surgery

A technique for determining the degree of fixation of the stapedial footplate, a quantitative Gelle, was described It is the author's experience that such tests are useful only if they can definitely establish whether the footplate is or is not fixed at all While the less rigidly fixed footplate apparently can be more easily *mobilized,* stapes surgery is indicated even in the case of a rigidly fixed stapes, since a fenestra ovalis can be made through the footplate

Questions were raised about the necessity of maintaining an intact ossicular chain for the surgical removal of the air-

# NEURALLY ISOLATED COCHLEA
(Abstract) *

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and
ARNOLD A GERALL,
University of Rochester,
Rochester, New York

Sectioning of the auditory nerve in the anesthetized cat abolishes or greatly reduces the P1-component of the neural click response This observation re-opens the problem of the origin of the several parts of the click response Experiments to determine the nature of these components were undertaken and were reported

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*The full paper will be published elsewhere

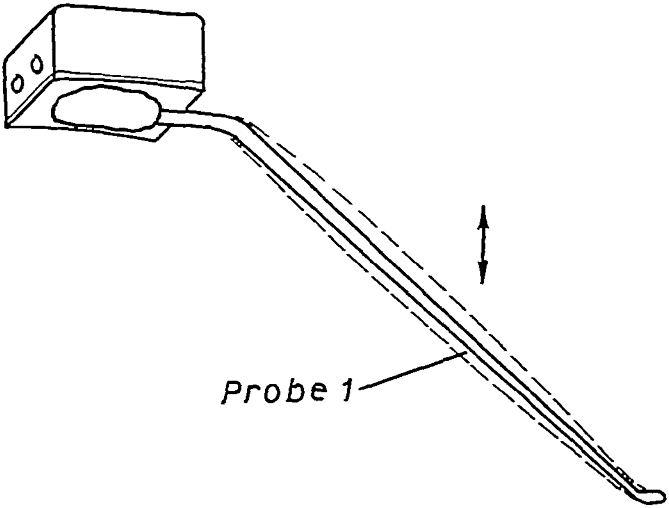
Probe 1

Fig 1.

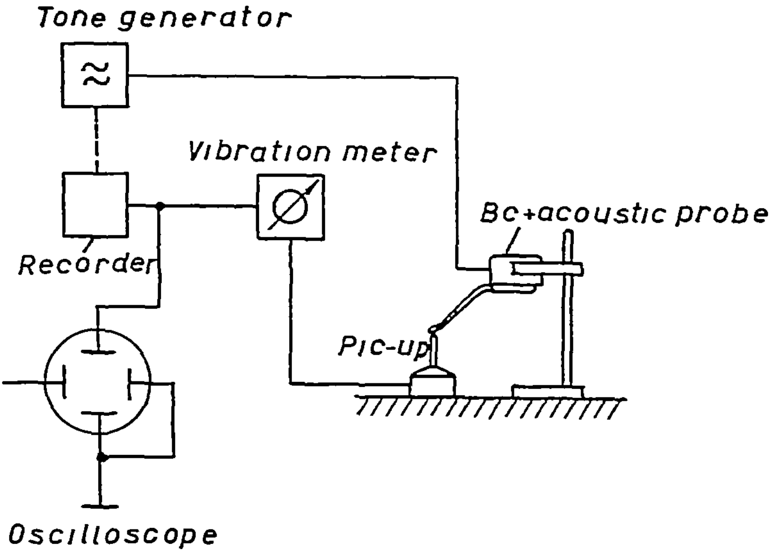
Tone generator
Vibration meter
Bc+acoustic probe
Recorder
Pic-up
Oscilloscope

Fig 2

bone gap, and a case was shown where, despite the fracture and removal of the crura, the post-operative hearing was better than normal It appears that there is not yet a predictable relationship between the pre-operative hearing test findings and the degree of hearing improvement achieved through stapes surgery

# THE ACOUSTIC PROBE AND THE DETERMINATION OF STAPEDIAL FIXATION

OTTO H MEURMAN,

University of Helsinki, Finland

In the February issue of *Acta Otolaryngologica,* 1957, I published a report on the use of an acoustic probe for determination of the degree of stapedial fixation The present paper is based, in the main, on the same clinical measurements and some additional technical studies

The work was undertaken to discover the possible value of the acoustic probe in studying the mobility of the ossicular chain prior to mobilization, and in particular to determine whether the stapes is rigidly, or only slightly, fixed to the oval window The pure tone audiogram mostly provides information as to whether the stapes is mobile or immobile Audiometric studies, however, do not reveal the degree of fixation

## ACOUSTIC PROPERTIES OF THE PROBE

For the clinical experiments an acoustic probe was used, consisting of an ordinary ear probe attached to the bone conductor of the audiometer, as illustrated in Fig 1 The acoustic properties of this probe were measured at the State Technical Research Institute The purity of tone depends essentially upon the pressure exerted by the probe If the pressure is small, impurity of tone results A thin probe vibrates on its own resonance frequencies, which changes very rapidly by loading the probe The velocity of the probe at various frequencies was tested with the apparatus shown in Fig 2 The curves in Fig 3 indicate that the probe, as well as the bone conductor, is most sensitive at about 500 c p s, where the velocity is greatest The amount of energy loss can also be seen from the curves when comparing the velocity coming through the probe with the velocity of the bone conductor itself Energy transmission is limited to about 0 1 per cent The second probe (see Fig 4), has a different construction the probe itself is thicker than the first and it is attached at right angle to the bone conductor Vibration here occurs along the length of the probe, transverse vibration being largely eliminated Sound transmission is thus entirely altered As shown in Fig 5, there is scarcely any energy loss between the bone conductor and the probe A probe constructed along these lines must be regarded as certainly the most suitable testing device, and it will be used in my further studies

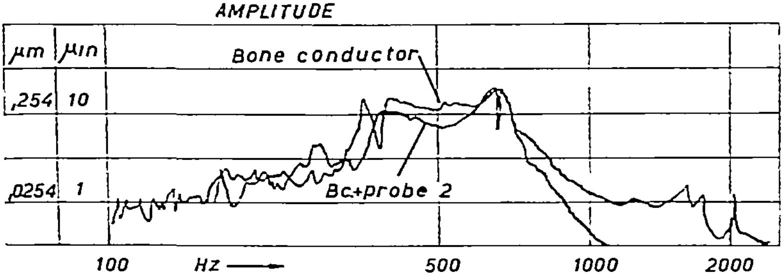

Fig 5

## CLINICAL OBSERVATIONS

A threshold curve was determined at 250, 500, 1000 and 2000 c p s, by gently touching the handle of the malleus just below the short process, with the acoustic probe Superficial cocaine anilin anesthesia was used To preclude error, the threshold values for the same frequencies were tested also by keeping the probe in the meatus without touching the meatal walls, malleus or tympanic membrane The values thus ob-

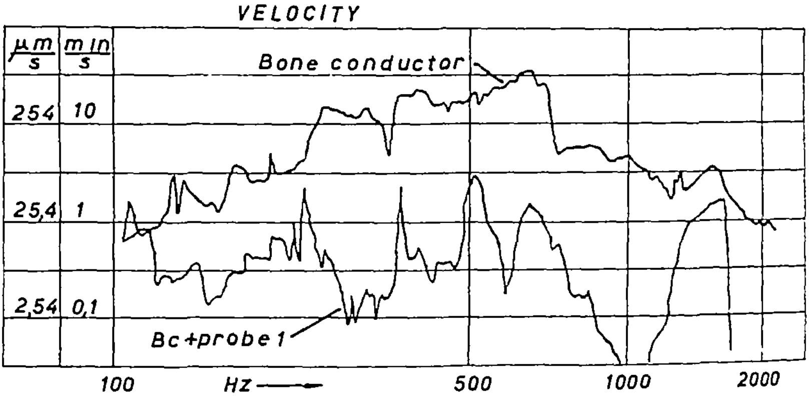
VELOCITY
μm/s
m in/s
254
10
25,4
1
2,54
0,1
Bone conductor
Bc+probe 1
100
Hz ⟶
500
1000
2000

Fig 3

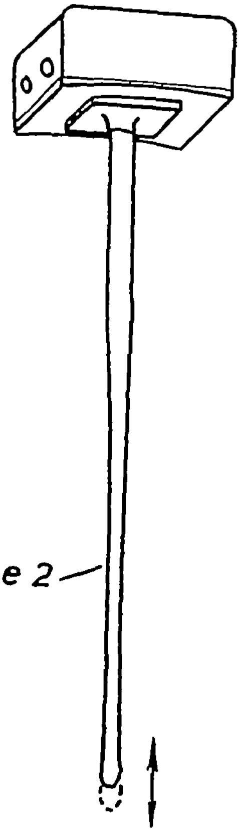
Probe 2

Fig 4

less It is also seen that in Group 1 the ossicle curve shows values considerably smaller than in Group 2 In the former group fixation of the stapes was slight Mostly it was fixed only at the anterior periphery Mobilization in these cases was easy and successful In Group 2, on the other hand, the stapes was extremely firmly fixed In some cases mobilization failed, in some it could be effected only by freeing both the anterior and the posterior periphery

## CONCLUSIONS

Clinical studies show that threshold audiograms, recorded by acoustic probe direct from the malleus handle, present values differing according to the degree of fixation If fixation is slight, the ossicle curve gives considerably smaller values than the air conduction audiogram If the stapes is solidly fixed, the ossicle hearing loss at the various frequencies is distinctly greater than in cases with slight fixation In the presence of only slight fixation, the direct contact between the vibrating probe and the ossicular chain causes vibration also in the stapes footplate, or at least in a part of it With an increase in the degree of fixation, the stapes functions more and more as a part of the labyrinthine wall, and its vibration is reduced in accordance From this it follows that, at least in certain cases, it is possible to determine the degree of fixation of the stapes preoperatively by means of an acoustic probe

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# DIRECT AUDIOMETRY IN AUDIOSURGERY*

(Abstract)

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FERNANDO ANTIOLI-CANDELA,
F OLAIZOLA
and
L SAFT,
Madrid, Spain

Modern audiosurgery deals not only with fenestration and tained were always considerably higher than those obtained from the malleus handle

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*This abstract was received and appeared on the official program but the authors were not able to be present to present the full paper

Normally hearing ears served for control purposes The average threshold curve obtained for these ears was taken as the zero curve, by which the hearing loss in the ossicle curves was calculated The series proper is based on 30 otosclerotic ears, 21 of them were operated upon by stapes mobilization after testing with the acoustic probe In these cases the preoperative ossicle curves could be compared with the degree of stapedial fixation noted at operation The following table shows the ordinary air conduction hearing loss and the relative ossicle hearing loss (OC) at 500 and 1000 c p s in two different groups of patients In the first group the stapes was slightly fixed, in the second it was rigidly fixed

TABLE I

GROUP 1

| Patient No | AC - Loss 500 c.p s | AC - Loss 1000 c p s | OC - Loss 500 c.p s | OC - Loss 1000 c.p s. |
|---|---|---|---|---|
| 1 | 40 | 35 | 0 | 5 |
| 5 | 60 | 60 | 25 | 30 |
| 15 | 50 | 45 | 20 | 20 |
| 16 | 55 | 55 | 30 | 20 |
| 18 | 50 | 40 | 10 | 20 |
| 19 | 60 | 60 | 15 | 5 |
| Mean | | | 16 5 | 16 5 |

GROUP 2

| Patient No | AC - Loss 500 c.p s | AC - Loss 1000 c p s | OC - Loss 500 c.p s | OC - Loss 1000 c.p s. |
|---|---|---|---|---|
| 2 | 54 | 60 | 35 | 60 |
| 3 | 50 | 45 | 40 | 30 |
| 7 | 60 | 50 | 45 | 55 |
| 8 | 65 | 65 | 60 | 45 |
| 9 | 50 | 55 | 30 | 40 |
| 11 | 60 | 60 | 30 | 35 |
| 13 | 55 | 55 | 40 | 35 |
| Mean | | | 40 | 42 9 |

Group 1 Stapes fixation slight
Group 2 Stapes fixation rigid

A study of the table readily shows, for one thing, that in Group 1 the air conduction loss is much greater than the ossicle hearing loss, whereas in Group 2 the difference is far region This is because the visual direction of gaze is oblique relative to the internal surface of the tympanic cavity, due to its characteristic inclination This tangential visualization also encounters the obstacles of the short process of the incus and both processes of the stapes

We have attempted to achieve a better visualization of the footplate by means of a lengthened, preaural incision in the anterior wall of the auditory canal just at the edge of the tympanic bone, which at this place forms the bony portion of the canal This permits the uncovering of the edge of the tympanic bone The lifting of the skin that covers both it and the capsure of the temporo-maxillary articulation further permits us to extirpate small or large portions of the bone with the drill Now we can adjust the visual angle so that it may be perpendicular to the footplate of the stapes

Further extirpation and laying back of skin permits enlargement of the visualized space so that the footplate may be projected frontally in the center of the visual field and may thus be manipulated more safely and under better control

## THE CARHART-SHAMBAUGH FORMULA USED FOR STAPES MOBILIZATION PREDICTION

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and
C OLAF HAUG,
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It has been generally believed and emphasized by Rosen,[1] Kos,[2] Sheer,[3] and others, that it appears impossible at this time to establish audiometrically a workable prediction of the result to be expected from the stapes mobilization operation It is pointed out that variations in oval window pathology resulting in stapes fixation in large part determine the feasibility of mobilization, and that the nature and extent of this fixation cannot be ascertained short of exploratory surgery stapedioclasia for otosclerosis, but also with every technique for the recuperation of any deafness caused by congenital defects in the sound transmission, traumatic lesions and suppurated chronic processes of same, and its healing sequels

With a view to reaching a more exact preoperative diagnosis, and providing beforehand the most adequate surgical technique, we usually carry out a direct audiometry by means of a plastic acoustic conductor connected to a micro-audiometer and placed either on the pathologic formations of the tympanic cavity or on the basic points of the sound conduction, thus enabling us to find out the highest or lowest integrity of the tympano-ossicular apparatus and the permeability of the windows

It also allows us, when performing a mobilization operation, to know more definitely when we obtain a total or partial mobilization of the stapes and the function of the round window

Similar findings can be achieved if we encounter remains of ossicles in the audiosurgery of atresias

## NEW APPROACH TO THE INCUDO-STAPEDIAL REGION FOR MOBILIZATION OF THE STAPES*

(Abstract)

LUIS GARCIA-IBANEZ,

Valencia, Spain

Our experience in mobilizing the stapes according to the approach of Rosen has not been good With that approach and working on the neck of the stapes, only one out of three patients who were operated upon achieved a result that was lasting and socially useful

Our attempts to work directly on the footplate of the stapes showed that it is difficult, with Rosen's approach, to achieve good exposure and visualization of the incudo-stapedial

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*This abstract was received and appeared on the official program but the author was not able to be present to present the full paper of the bone-air gap. As shown by the results in Tables I and II, the average amount by which this closure fails in our series is 14.6 db.

This figure compares very favorably with the differential of 15 db between the post-operative air average and the pre-operative bone average (or 25 db from the corrected bone average), which serves as a basis for the C-S formula. In the fenestration prediction it represents the irreversible residual of hearing deficit resulting from surgical disruption of the impedence matching ossicular chain mechanism.

TABLE III

Stapes Mobilization—Chances for Closing Air Bone Gap Based on Series of 100 Cases

| | |
|---|---|
| % Closed Air Bone Gap | 12.9 |
| % Closed Air Bone Gap within 5 db | 18 |

Table III further illustrates the small percentage of possibility of closing the bone-air gap completely or within 5 db. This differential between the post-operative air result and the pre-operative bone, which in our series has been so much like that found in the fenestration situation, requires further study to establish an explanation. After stapes mobilization, of course, the ossicular mechanism has not been sacrificed and, theoretically, if complete mobilization is successful, hearing should be restored to the level of the pre-operative bone conduction threshold.

Middle ear pathological changes present at the time of operation, or following mobilization attempts, probably prevent this theoretical bone-air closure. These changes might include friction in movements of the stapedial foot plate, caused by bony spicules and other irregularities of outline following lysis of the stapes, stretching of the incudo-stapedial or incudo-malleolar joint, fibrosis of the annular ligament, tension changes in tympanic membrane and incomplete mobilization of the stapes footplate. We must bear in mind that mechanical mobility of the stapes does not necessarily insure adequate physiological mobility of the inner ear fluids.

We realize that the otosclerotic focus may result in varying degrees of stapes ankylosis, sometimes preventing successful mobilization, and the difficulties involved in establishing an accurate formula comparable to the fenestration prediction, however, we felt that a study of one of the fenestration prediction formulas on a series of stapes mobilization cases employing the same selection technique by the same audiologist-otologist team, might provide a guide as to what could be expected from the procedure

TABLE I

Stapes Mobilization—Closing the Air Bone Gap

| | Actual Result | CS Prediction |
|---|---|---|
| Average Post Op Level | 27 9 db | 28 3 db |
| Average Pre-Op Bone Cond | 13 3 db | 13 3 db |
| | 14 6 db | 15 0 db |

TABLE II

Stapes Mobilization—Closing the Air Bone Gap
Based on Series of 100 Cases

| | |
|---|---|
| 10 Cases—Better than bone conduction avg by | +4 5 db |
| 2 Cases—Same as bone conduction | 0 db |
| 81 Cases—Poorer than bone conduction by | -14 66 db |
| 7 Cases—Failures | |
| 100 | |
| Total Difference 100 Cases | -14 6 db |

From a study of 100 consecutive fenestrations in a series of 500 cases, the Carhart-Shambaugh[4] formula was found to predict the post-operative result with a high degree of accuracy We have continued to use this formula in all pre-operative audiological evaluations, even though the stapes mobilization was to be the elected procedure A previous evaluation of an earlier series of the first 100 stapes operations suggested the possibility of the C-S formula for predictive purposes

It has been our experience that stapes mobilization attempts do not usually restore complete efficiency of the conductive mechanism, as would be demonstrated by closure have the fenestration before the four months' post-operative test was done

While we are aware that our selection has eliminated some unfavorable results, it has also eliminated an equal number of favorable results, as illustrated in Table V

Table VI shows that the sample used was typical of the range of pre-operative levels ordinarily encountered in otosclerotic patients

TABLE IV

Stapes Mobilization—Comparison 1st Post Operative Test 1 to 2 Months Following Mobilization with 2nd Post Operative Test 3 to 4 Months Following Mobilization
Based on Series of 100 Cases

| | |
|---|---|
| 1st Post Operative Average Level | 27 94 db |
| 2nd Post Operative Average Level | 29 28 db |
| Total Average Difference | 1 34 db |
| 1st Post Operative Average Gain | 20 56 db |
| 2nd Post Operative Average Gain | 19 22 db |
| Total Average Difference | 1 34 db |

TABLE V

Stapes Mobilization—Post Operative Results—96 Eliminated Cases

| More than 10 db gain and better than 35 db level<br>Good | 35-40 db level and more than 10 db gain or 25 35 db level and 6 10 db gain<br>Partial | Less than 11 db gain and poorer than 35 db level or less than 6 db gain any level<br>Bad |
|---|---|---|
| 31 Cases | 14 Cases | 33 Cases |
| 23 69 db level<br>22 7 db gain | 35 5 db level<br>12 21 db gain | 51 db level<br>1 97 db gain |

Our average post-operative stapes level, as compared to the average Carhart-Shambaugh fenestration predicted level, is shown in Table VII The levels of 27 94 db and 28 39 db represent an average difference of only 39 db In Table VIII the range of variance from perfect prediction is plotted It reveals that 48 per cent of the cases were either exactly predicted or were within 5 db of perfection, 76 per cent of

It is our feeling, that given a standardization of pre-operative evaluation involving the same audiologist, and of surgical procedure by the same operator, the main remaining variable in the application of C-S formula is the nature and extent of the otosclerotic pathology which would permit or prevent mobilization of the stapes

From an evaluation of the distribution of mobilization failures in an adequate series, one may be able to predict the percentage of cases which will defy successful mobilization, because of the anatomy and extent of otosclerotic pathology Then, eliminating this group and leaving those who can be mobilized, one may predict, using an audiometric formula such as the C-S, what the expected level will be

In order to investigate this possibility the most recent 100 cases of stapes mobilization, in which one month and four months' post-operative results were available, were studied as to the correlation of post-operative result and C-S prediction The most recent 100 were chosen in order to eliminate the variable of changing surgical technique, and to take advantage of the factor of surgical experience

The surgical technique for stapes mobilization used in this series of cases was a variation of the original Rosen[5] technique, as modified by House[6] Mobilization maneuvers are made through the capitulum of the stapes with curved Rosen explorers If this maneuver does not result in mobilization, attempts are made to mobilize the stapes via the footplate, as described by Rosen Fenestration of the footplate was not attempted in this series Surgical audiometry, adapted from the Goodhill[7] technique, was used in all cases

We chose these cases with both one month and four-month post-operative results because we felt that it was important to establish the degree of stability of the results used in this study Table IV shows that the average change from first post-operative test to second was only 1 34 db

This selection of necessity covered a large group of cases, because, although every patient was contacted for retesting, many failed to return for one of these tests, or went on to our cases were within 10 db of the Carhart-Shambaugh predicted level Range of variance is further depicted in Table IX, 53 results were better than the C-S predicted level by 9 3 db, and 29 were poorer than the C-S level by 7 7 db, making a total of 82 cases that differed from the exact fulfillment of the prediction by an average of 8 3 db There were 11 who obtained a level identical to the prediction, and 7 surgical failures Twelve cases had a failure result by our standard of less than 11 db gain, together with poorer than 35 db level, or less than 6 db gain any level, however, five of these cases were predicted to be failures, and were classified as selection failures and included in the predictive comparison On the other hand, seven had a good prediction and actually achieved a failure, and these were classified as true surgical failures and eliminated from the comparison

TABLE IX.

Stapes Mobilization—Post Operative Levels Compared to Carhart Shambaugh Predicted Levels Based on Results of 100 Cases

| No Cases | | |
|---|---|---|
| 53 | Better Than CS Predicted Level by | 9 3 db |
| 29 | Poorer Than CS Predicted Level by | 7 72 db |
| 82 | Differ from CS Predicted Level by | 8 3 db |
| 11 | Same Level as CS Predicted Level | 0 db |
| 7 | Failures | |
| 100 | Total Cases | |

TABLE X.

Stapes Mobilization

| Predicted Poor Result<br>Less 11 db gain and<br>Poorer 35 db level<br>any level | | Good Prediction<br>More 10 db gain and<br>Better 35 db Level<br>or More 30 db gain<br>any level | |
|---|---|---|---|
| Fulfilled | Not Fulfilled | Fulfilled | Not Fulfilled |
| 5 Cases | 6 Cases | 60 Cases | 10 Cases |
| 11 Cases | | 70 Cases | |

Table X demonstrates the success of the C-S formula in

### TABLE VI

Stapes Mobilization—Range of Pre-Operative Level
Based on Series of 100 Cases

| | |
|---|---|
| 76 80—1 | 1 |
| 71 75—11 | 2 |
| 66-70—11 | 2 |
| 61 65—11111 11 | 7 |
| 56 60—11111 11111 11 | 12 |
| 51 55—11111 11111 11111 11 | 17 |
| 46 50—11111 11111 111 | 13 |
| 41-45—11111 11111 11111 11111 | 20 |
| 36-40—11111 11111 11111 1 | 16 |
| 31 35—11111 111 | 8 |
| 26 30—11 | 2 |
| | 100 |

### TABLE VII

Stapes Mobilization Post Operative Results Compared to
Carhart Shambaugh Predicted Results
100 Case Series
Results based on 1st Post Operative Test, 1 to 2 Months After Mobilization

| | |
|---|---|
| Average Pre-Operative Level | 48 50 db |
| Our Average Post Operative Level | 27 94 db |
| CS Average Predicted Level | 28 33 db |
| Total Average Difference | 39 db |
| Our Average Post Operative Gain | 20 56 db |
| CS Average Predicted Gain | 20 17 db |
| Total Average Difference | 39 db |

### TABLE VIII

Stapes Mobilization
Based on Series of 100 Cases

| | | | |
|---|---|---|---|
| Better Than CS Pred Level by— | | | |
| 21 db —111 | 3 | | |
| 11 20 db —11111 11111 1111 | 14 | | |
| 6 11 db —11111 11111 111 | 13 | | 76% |
| 1 5 db —11111 11111 11111 11111 111 | 23 | 48% | |
| Same as CS Pred Level—11111 11111 1 | 11 | | |
| Poorer than CS Pred Level by— | | | |
| 1 5 db —11111 11111 1 | 11 | | |
| 6 10 db —11111 11111 111 | 13 | | |
| 11 20 db —111 | 4 | | |
| 21 db —1 | 1 | | |
| Surgical Failures—11111 11 | 7 | | |
| | 100 | | |

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# AUDITORY FATIGUE AND OCCUPATIONAL DEAFNESS *

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## INTRODUCTION

In the last several years studies dealing with the effect of noise on man were published by the co-workers of the Leyden Otological Clinic J van Gool studied the methods of recording auditory fatigue and the dependence of the pattern of the acoustic dip on frequency, intensity and exposure time of the stimulating tone H A van Leeuwen reported on the occurrence of noise trauma and noise deafness in groups of employees in different kinds of factories C Rol, together with A Spoor, gave the results of laboratory studies on the traumatizing effect of steady and nonsteady sounds A difference between the Leyden investigations, and all previous studies such as the well-known works of Temkin (1933), Børge Larsen (1939), Rosenblith (1942), Kristensen (1946), Kryter (1950), and the report of the American Standards Association Z 24-X-2 is the use of continuous-frequency audiometry instead of octave audiometry predicting the extremes of good and poor results  Of the 11 cases predicted for a very poor result, five were fulfilled and six not fulfilled  Of the 70 cases predicted for a good result, 60 cases were fulfilled and 10 cases not fulfilled

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In summary, it has been shown that the Carhart-Shambaugh formula for predicting fenestration results may, according to this series of cases, have value in predicting the stapes mobilization result  It was shown that the average difference in predicted and actual levels was low, and range of variance relatively small  It was demonstrated further that the average amount by which our results fail to close the bone-air gap is almost identical to that which is expected in using the Carhart-Shambaugh formula for fenestration prediction  The number of cases achieving levels close to the prediction was great, and the formula's ability to predict good results appeared significant

It is emphasized that further study is necessary to explain all the reasons for failure to close the bone-air gap in the majority of cases  Limitations in the formula's use have been illustrated by the fact that although the average difference in predicted and actual result was small, since better and poorer prediction results tend to cancel each other, individual cases may be considerably off from the prediction, also, though the formula had considerable success in predicting good results, it was only 45 per cent effective in predicting very poor results (5 out of 11)

Although much more study is necessary before we will achieve a stapes formula with the predictive ability of the fenestration formulas, we feel that the Carhart-Shambaugh formula, if cautiously interpreted, will serve as a better guide to the expected result in the mobilized cases than is otherwise now available

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be detected, and with some additional measurements on higher levels the exact pattern can be established

## EXACTNESS OF CONTINUOUS AUDIOMETRY AS COMPARED TO OCTAVE AUDIOMETRY

Apart from the greater information obtained by continuous audiometry, because the exact pattern of a hearing loss is established, the reproduceability also proved to be superior Alternately three continuous and three octave audiograms were made of the same test person by van der Waal A great number of these audiograms were studied statistically The mean average standard deviation in continuous audiometry proved to be 2 41 db, whereas in octave audiometry, 3 68 db

## BACKGROUND NOISE

The great practical difficulty in obtaining reliable audiograms in factories is the fact that the quietest room is not comparable to a specially built silent room of an acoustic laboratory, however, bringing the factory workers to the institute is generally not convenient The examiner, working in a relatively noisy surrounding and finding threshold anomalies, must know what part of the measured hearing loss is due to masking by background noise and what part can be attributed to an acoustic trauma

An investigation of this problem was made by Spoor In a sound-treated room, audiograms of persons with normal hearing were taken during exposure to different kinds and levels of noise, *e g* white noise, industrial noise and octave band noise The audiometer was checked by using as a reference value the average continuous audiogram of 20 young persons without evidence or history of hearing damage It appeared from these investigations, in confirmation of earlier publications, that the audiogram of a normal test person is already disturbed by a noise level of 20 db and more Using telephones with rubber cushions, giving 10-20 db isolation *the acceptable noise level* in the room will be 30-40 db In most circumstances this level can be realized for high tones by simple noise isolation measures, but it is often impossible for the low tones, consequently for low tones the unavoidable

## CONTINUOUS AUDIOMETRY

In continuous audiometry a sweep tone is presented to the patient at a certain intensity level  The patient's hearing threshold is noted by asking him to indicate at which frequency he begins to hear the sweep tone, and at which frequency the hearing ends  By doing this at different intensity levels a complete and very accurate audiogram can be made in a short time  The procedure is the contrary of octave audiometry, in which the threshold of some selected frequencies is determined by means of a changing intensity  Thus greater and more exact information can be obtained

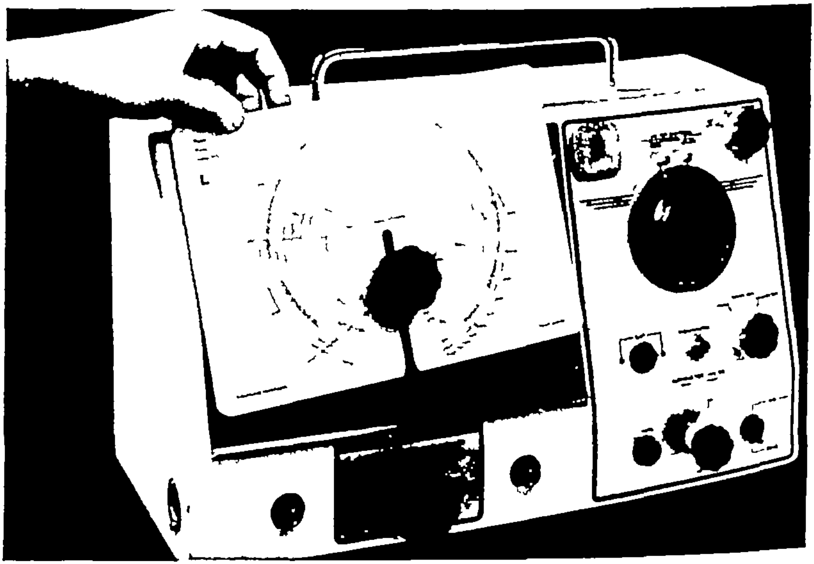

Fig 1  Continuous audiometer with direct recording on the audiocard (Peekel)

The Peekel-audiometer is specially built for continuous audiometry  Compensation is made for the low and high frequencies, so that the zero-level of the instrument coincides with the threshold level for normal young persons  As from 200-8000 c/s in one sweep any level above thresholds can be tested, this arrangement makes the audiometer ideal for screening  If somewhere a hearing loss, such as a beginning acoustic trauma, exists, the localization of this loss will always posure time, however, over 15 minutes does not increase the extent of the dip The conclusion from this fact is that in longer exposure, auditory fatigue depends upon intensity and frequency alone, thus in factory workers the resulting trauma might be limited by the existing noise level, and might not depend on the number of years of exposure Pure tones and noise bands around and above 2000 c/s possess a greater traumatizing effect than lower frequencies of the same intensity above threshold

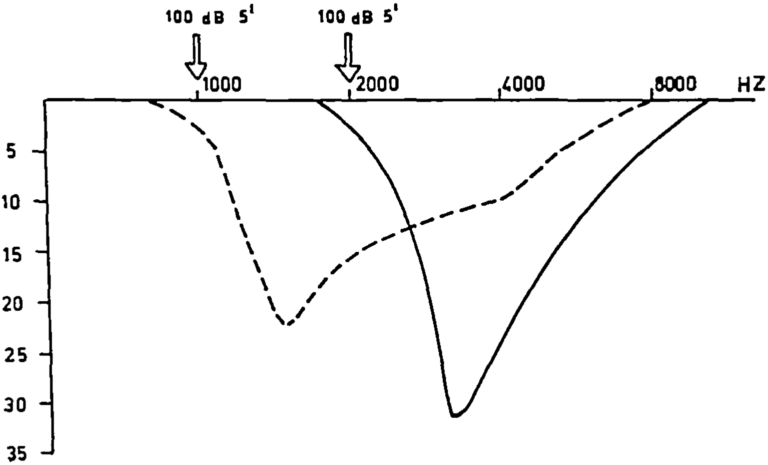

Fig 2 Pure tone dips caused by 1000 c/s and 2000 c/s tones of the same intensity and duration.

From these general properties of the acoustic dip, one may conclude that the notion of a special sensitivity of the $C_5$ region is erroneous Consequently no theories trying to explain the $C_5$ dip are needed The origin of the illusion of a preference of the region around 4096 is clearly the result of the measuring at this frequency in octave audiometry Accordingly, the maxima of industrial noise traumata can be located at any frequencies between 2000 and 7000 c/s

## A THEORY ON THE ORIGIN OF THE ACOUSTIC FATIGUE AND TRAUMA

Perhaps the tonal dip might be explained by the following noise level is mostly higher than is acceptable, and thus an inaccuracy of the audiogram must be reckoned with By establishing the threshold shift of normal persons under these unfavorable circumstances, a reference value for pathological audiograms, taken under the same circumstances, can be obtained Hearing losses as large as, or smaller than, this threshold shift cannot be measured For instance, when a dip of 10 db is measured, and the threshold shift by background masking in this frequency region is 15 db, then the real dip, when measured in a silent room, would be 25 db The average audiogram of 20 normal young persons, taken in a relatively silent factory room, having a background noise level of less than 40 db in each octave band, proved to be for the higher tones in good accordance with the curves of Dadson and King, and Wheeler and Dickson Under 100 c/s an apparent hearing loss, due to low-pitched background noise was present In experienced listeners the differences between the readings in a silent room and in the presence of a background noise are smaller than in unexperienced listeners

## EXPERIMENTS WITH SINGLE PURE TONES

Auditory fatigue is characterized by a temporary threshold rise of a typical pattern—a tonal dip The threshold at the frequency of the stimulating tone itself is not, or only slightly disturbed The maximum of the dip is situated approximately one-half octave above this frequency For dips caused by 1000 c/s and higher tones the slope of the dip on the side of the lower frequencies is steep and on the other side much more gradually, showing some small depressions The steepness, and thus the place of the maximum of the dip in regard to the stimulating frequency, depends on the size of the dip Small dips are bowl-shaped with their maximum on a higher frequency The extent of the dip depends on the sensitivity of the testees and the traumatizing power of the stimulus In steady pure tones this power depends on intensity, frequency and up to a certain limit on the exposure time Thus the same small dip can be obtained when using a certain tone of high intensity during a short time, or of low intensity during a long time Lengthening of the ex-

Ranke and Reboul, the maximum of this distortion is situated about one-half octave above the stimulating frequency, thus on the place of the maximum of the dip We assume that this part is damaged by such an inadequate stimulation The amplitude of the swinging is higher nearer to the stimulating frequency, which fact agrees with the slope of the curve and the place of the maximum of the dip Notwithstanding the relatively large movements, this inadequate form of stimulation causes no hearing sensation Perhaps the fact that in high intensities a pure tone sounds more or less impure, is due to this distortion

Frequent repetition of the reversible auditory fatigue, without sufficiently long period of recuperation, results in an irreversible lesion of the organ of Corti, that is, in an acoustic trauma

## FATIGUE CAUSED BY PURE TONES OR BY A WHITE NOISE

The effect of stimulation by two pure tones proved to be the combination of two separate dips Consequently it might be possible that, if an employee is traumatized by a high pitched noise and he is transferred to a department having a low pitched noise, an additional trauma for lower frequencies will result Fatigue caused by one-third octave bands proved to be similar to the effect of pure tones

As a white noise is the combination of a great number of frequencies, the resulting trauma will depend upon the sensitivity of the ear and the traumatizing power of the different frequencies The frequency bands around 2000-3000 c/s are dangerous, because the threshold of the ear is low, and the traumatizing power of these higher tones is great The trauma of a white noise proved to be a broad bowl shaped dip, extending from about 3000-7000 c/s, consequently, in an industrial noise the energy in the 2000-3000 c/s band is of great importance

## EXPERIMENTS WITH PULSE TONES AND PULSATING NOISES

Rol and Spoor studied the traumatizing power of non-steady sounds as compared to the better known traumatizing theory The stimulation pattern of the basilar membrane by a pure tone, as established by its masking effect, betrays what happens when acquiring a tonal dip The part around the stimulating frequency is strongly but adequately stimulated Clearly this physiological, adequate stimulation results in the hearing of a pure tone, and none, or only a small threshold rising, can be detected afterwards, moreover, the perstimulatory loudness adaptation is present around this stimulating frequency, and not above or below

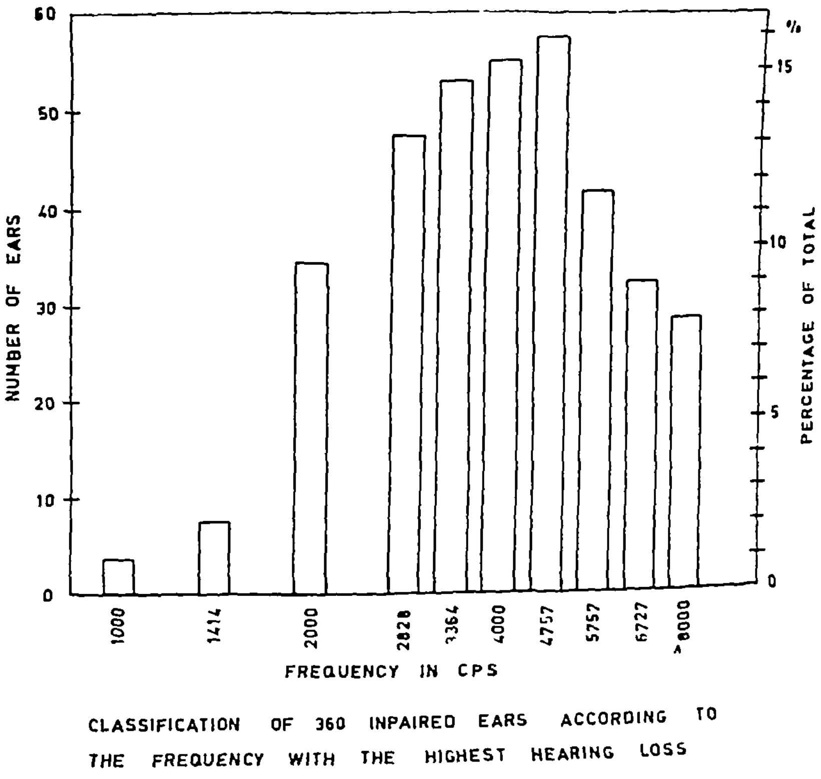

Fig 3 Classification of 360 noise traumata according to the frequency with the highest hearing loss

As is demonstrated by von Bekesy the basilar membrane between the stimulating frequency and the windows suffers distortion due to swinging According to the calculations of

Intermittent stimuli are less traumatizing than continuous stimuli of the same calculated overall intensity

Increase of the pulse duration, the pulse-rate being constant, causes a greater increase of trauma than would be expected from the corresponding increase of the overall-intensity (see Fig 5)

In the same way it was established that increase of the pulse-rate, the pulse-duration being constant, has a greater influence on the traumatizing power than on the calculated overall-intensity of the tone (see Fig 6)

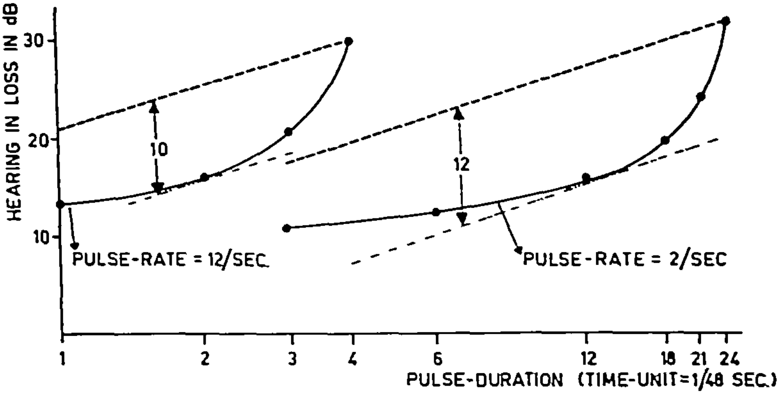

Fig 5 Hearing losses caused by intermittent 2000 c/s stimuli with pulse-rates of 2 and 12 per sec. The upper-dashed lines indicate the hearing losses corresponding to the continuous stimuli of the same overall-intensities

The difference between the trauma caused by an intermittent pure tone and that caused by a continuous one of the same calculated overall intensity was maximal, *viz* 7 to 12 db for a pulse interval ratio of about 1 1 When keeping the pulse interval ratio constant, it appeared that a pulse-rate of 8 per second is more harmful than one of 2 per sec If both noise and superimposed peaks are traumatizing, the effect of the total noise proved to be equal to the sum of the traumatizing powers of the components

The well-known deafness risk criteria are calculated from the threshold curve of the ear and from the greater trauma-

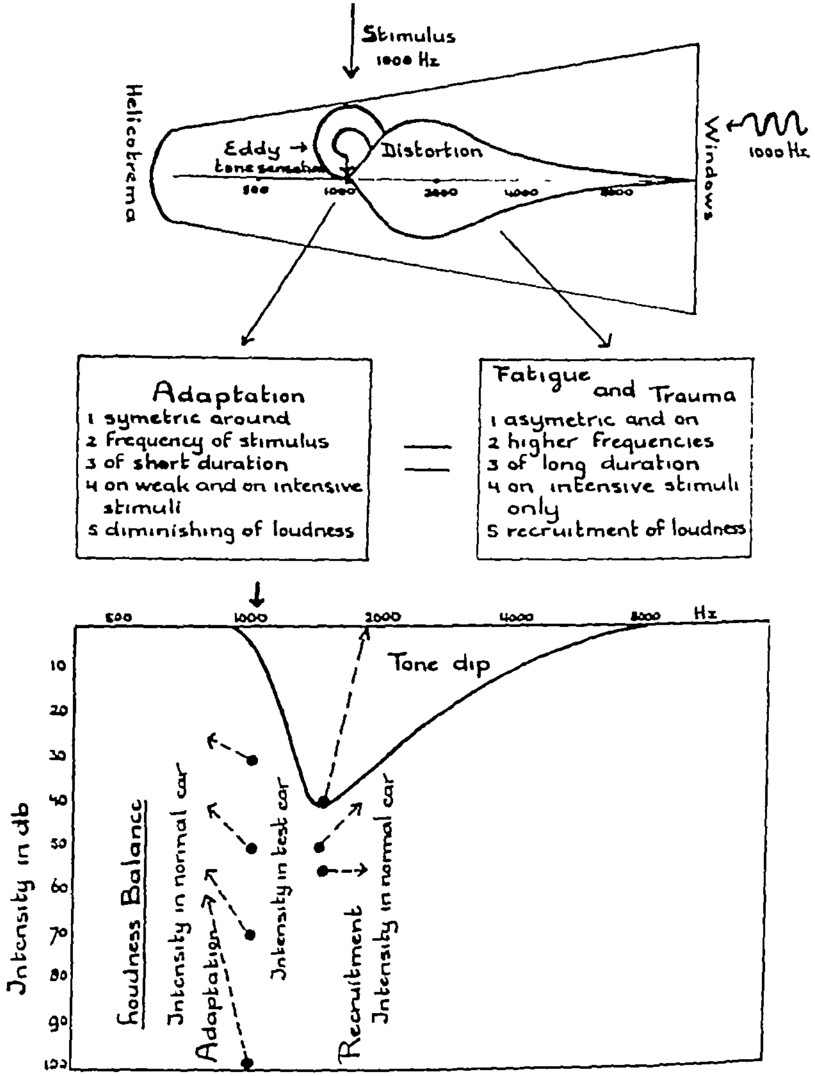

Fig 4 Schematic representation of cochlear mechanisms underlying adaptation and fatigue.

power of steady sounds. Intermittent pure tones, an intermittent white noise, synthetically constructed sounds imitating pulsing factory noises, and the recorded noise of a pneumatic drill, were used. It appeared that a sound-level meter, whether or not combined with band filters, does not give exact values for the traumatizing power of pulsating sounds

## INDIVIDUAL DIFFERENCES IN SENSITIVITY TO NOISE

It is a fact of common experience that among workers who are exposed to the same noise intensities, considerable differences in acoustic trauma exists Even the difference between the left and right ear of an employee can be very great

As we mentioned above, the tolerance curve (see Fig 7) may give us an idea of the traumatizing threshold of different subjects Usually, however, an above threshold method is employed, either by measuring the dip caused by a pure tone or by a noise In order to study this problem, van Leeuwen exposed 108 ears to 2800 c/s tone of 100 db during three minutes As a tonal dip changes very rapidly in size, the resulting dip was measured by means of continuous audiometry in one minute, beginning one-fourth minute after the cessation of the stimulating tone

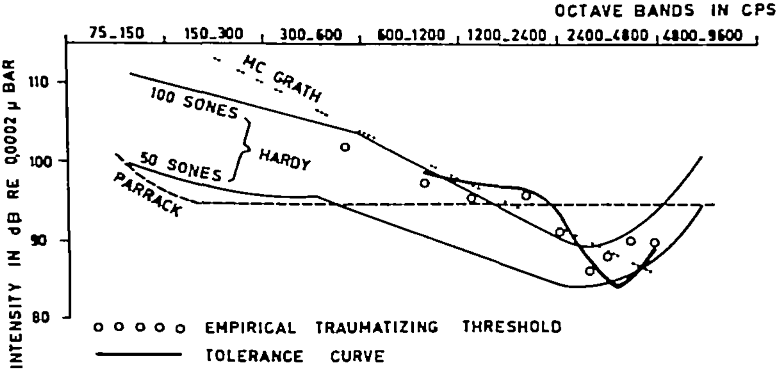

Fig 7 Deafness risk criteria, empirical traumatizing threshold and tolerance curve

| Threshold shift in db stimulus 2800 c/s 100 db 3 minutes | | No of Ears |
|---|---|---|
| 0 | -2-+2 | 26—24% |
| 5 | 3- 7 | 27—25% |
| 10 | 8-12 | 33—31% |
| 15 | 13-17 | 8— 7% |
| 20 | 18-22 | 7— 6% |
| 25 | 23-27 | 4— 4% |
| 30 | 28-32 | 3— 3% |

tizing of the high tones In order to establish this line experimentally Rol determined, in a number of testees for several tones, the minimum stimulation necessary to cause fatigue This empirically obtained curve differs, especially for the so important 2000-3000 c/s band, from the theoretically calculated curves (see Fig 7) It is known that the social validity for hearing of speech depends for a great deal on the range above 1500 c/s Thus, especially, excess of energy in the 1000-3000 c/s band will endanger the speech intelligibility

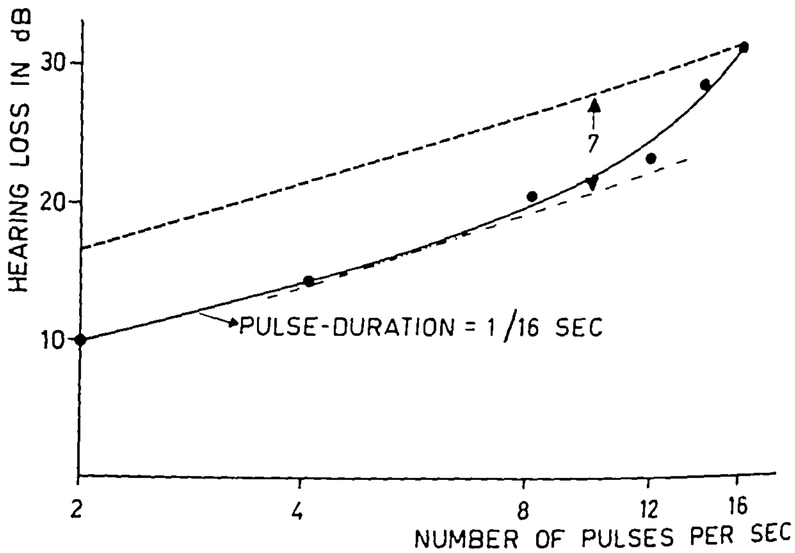

Fig 6 Hearing losses caused by intermittent 2000 c/s stimuli with a pulse-duration of $\frac{1}{16}$-second The upper line indicates the hearing losses corresponding to the continuous stimuli of the same overall-intensities

An attempt was made to establish this tone-sensitivity individually and in a quick and easy way Departing from the supposition that a tone becomes uncomfortable when the traumatizing threshold is reached, we asked our testees to indicate at which intensity a pure tone acquires an impure and sharp character Indeed, the curve in this way obtained, the tolerance curve, proved to be a good criterion for the individual sensitivity of noise (see Fig 7)

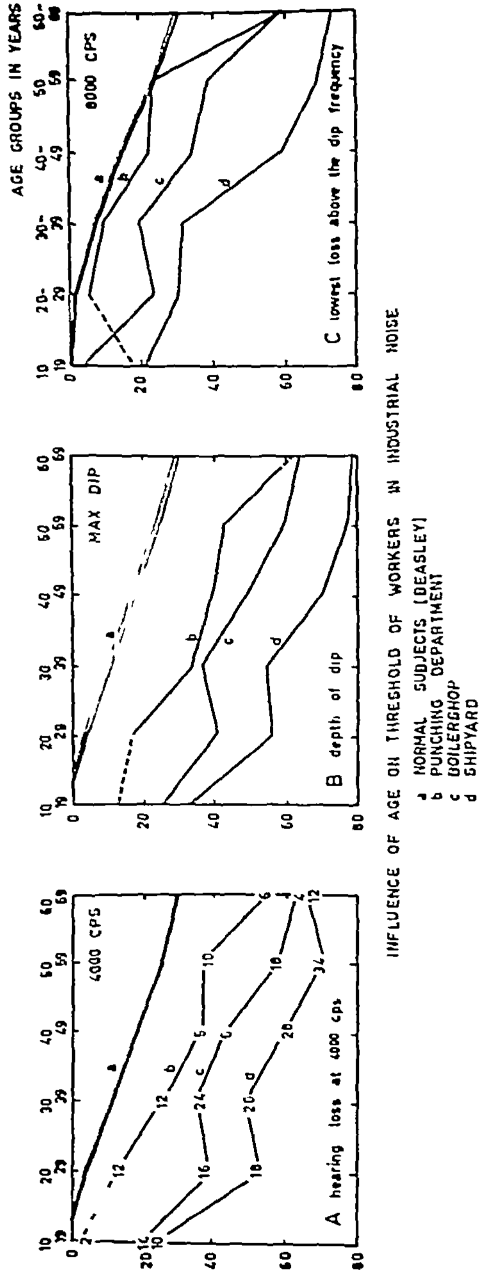

Fig 9 The influence of age on the hearing of employees in different departments.

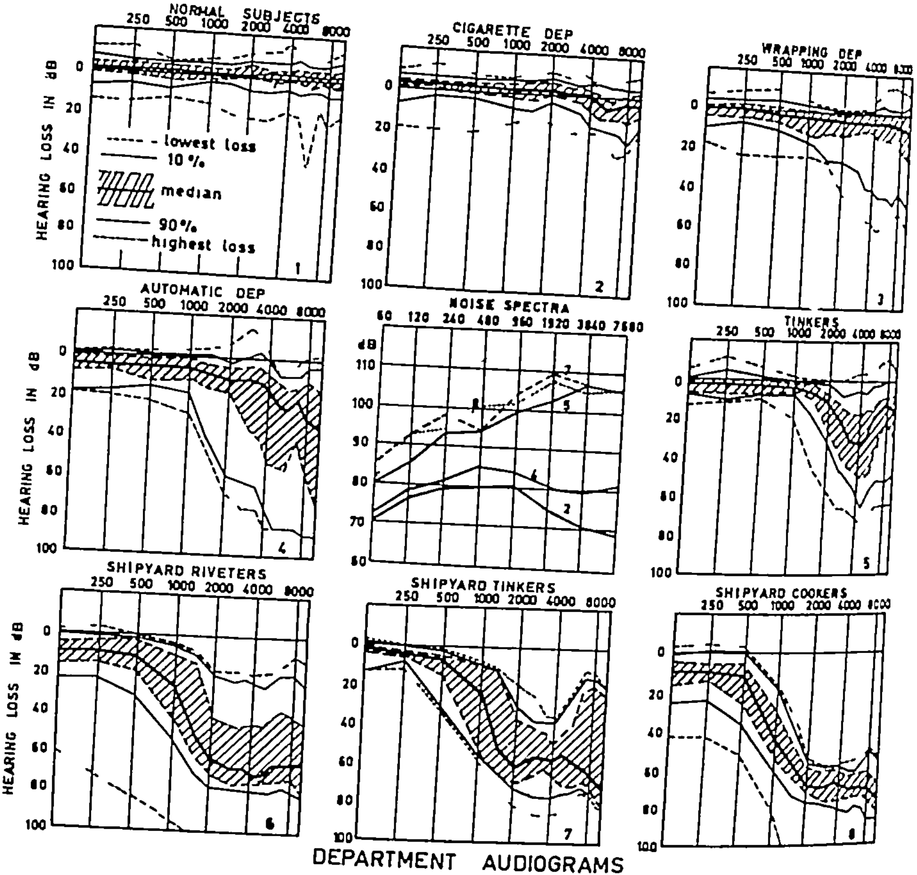

Fig 8 Combined audiograms of employees in departments with different noise levels

From these results we may conclude that considerable individual differences in sensitivity exist Against 24 per cent without threshold shift, 20 per cent proved to have a threshold shift, varying from 15-30 db

## NOISE TRAUMA AMONG FACTORY WORKERS IN DORDRECHT

In order to study the correlation between industrial noise level and resulting hearing loss, van Leeuwen classified 279

## SUMMARY

From our studies we may conclude that a certain average hearing loss belongs to a certain noise level After some months of exposure the amount of hearing loss hardly depends on the exposure time any more, but mainly on the noise level to which the factory worker is exposed In a relatively short time a trauma is acquired corresponding to the noise level, and thereafter, from this cause the hearing loss does not increase very much. A greater damage may occur when the employee shifts work to a department with a higher noise level or with another pitch. When in course of time presbycusis develops, hearing loss from this cause is added to the existing acoustic trauma Thus, a noise trauma acquired in youth may be unnoticed, but at a higher age this same trauma may be the cause of a hearing impairment for speech This consideration may have important legal consequences

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employees of ten noisy departments of six different factories on the Isle of Dordrecht The audiograms of the employees of each department were combined by considering the median curves and checking them statistically with a group of normal controls

It appeared that these department audiograms could be classified according to the prevailing noise levels This fact agrees with the above mentioned conclusions, that, generally speaking, the size of the trauma depends mainly on the quality and intensity of the stimulus, and not on the time of exposure to noise

In comparing the audiograms of newly appointed employees after a day's work, and the next morning, their capacity for recovery could be established In those who worked some years in a certain department, this recovery was practically absent, moreover, the very important fact was found, that the post-working audiograms of the newly appointed workers resembled closely those of the older employees This observation suggests that repeated acoustic fatigue results in a permanent trauma of the same size From this supposition we may expect that in each department the mean audiograms of different age groups, corrected for presbycusis, should present the same degree of trauma, particular for that department This conception proved, indeed, to be substantially true, only a slight deterioration occurring in the course of the years, which is not accounted for by presbycusis

From these observations, too, the important fact appeared that the permanent trauma is already acquired after a relatively short exposure time

Van Leeuwen calculated the average degree of trauma in groups of workers of about the same exposure time to the same noise level, in order to see whether there was an increase in loss in the groups with longer exposure to noise Since longer exposure and higher age are inevitably linked together the influence of presbycusis was eliminated by correcting the individual audiograms It appeared that most of the damage is done the first year of exposure to noise if the intensity of the exposure stimulus were raised or lowered

## METHOD AND PROCEDURE

Six listeners, ranging in age from 23 to 35 years, served in this experiment All had normal hearing and all data were collected monaurally, using the right ear

A PDR-10 earphone, which was encased in a doughnut-type cushion (NAF-48490-1) and mounted on a head band, was used to produce pure tones and noise The apparatus permitted the measurement of quiet absolute thresholds, the measurement of masked thresholds,* and the exposure of the ear to intense noise The test tone was generated by an audio oscillator The output of the oscillator was fed to an electronic switch, two attenuators in tandem, a mixer, a matching transformer, and then it was terminated by the earphone The output of a noise generator was passed through an attenuator to an amplifier For the measurement of masked thresholds, the output of this amplifier was fed through a matching transformer to the mixer in the tone circuit When the noise was to be used as an exposure stimulus, the output of the amplifier was put directly across the earphone Only high fidelity components were used, and switching devices allowed the experimenter to select the appropriate circuit and to keep all terminals properly loaded

Each listener was run individually in eight experimental sessions At each session, the absolute threshold at 4000 c p s was determined, the listener was exposed for three minutes to a noise of uniform spectrum level (60-7000 c p s ), and the recovery of the threshold at 4000 c p s was traced for 13¾ minutes The first determination of a post-exposure threshold was completed 15 seconds after the cessation of the noise During the remainder of the session, a threshold measure was completed every 30 seconds

At each session a different level of noise was used There were eight levels, which ranged in overall intensity from 85 db to 120 db (*re* 0 0002 microbar) in steps of five db These

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*The data for the masked thresholds are not reported

# TEMPORARY HEARING LOSS AT 4000 CPS AS A FUNCTION OF A THREE-MINUTE EXPOSURE TO A NOISE OF UNIFORM SPECTRUM LEVEL *

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Bloomington, Ind

## INTDODUCTION

The results of several experiments indicate[2 3 5 6 7 10] that the form of the function relating temporary hearing loss to the intensity of the exposure stimulus is complex As the intensity of the exposure stimulus is increased from a low value, temporary hearing loss remains at or near zero With further increases in intensity, the amount of loss at first positively accelerates, and then increases linearly up to high intensities At the highest intensities, temporary hearing loss *may show no further increase, or it may,* in fact, decline, with an increase in the intensity of the exposure stimulus This experiment was designed to provide further information on this relationship, as well as to help answer the following questions

*1* How does the relationship between temporary hearing loss (THL) and intensity differ from listener to listener?

*2* How does this relationship change as the threshold recovers?

It is well-known that wide individual differences in THL are observed when all listeners are exposed to the same stimulus[1 8 9] Answers to the two questions listed above would enable one to predict how the same individuals would differ the noise was defined as the single measurement, which was completed then The next two measurements, which were completed 45 and 75 seconds after exposure, were averaged to define the post-exposure threshold at 1 minute after the cessation of the noise The next four measurements of the threshold were averaged to define the post-exposure thresholds at 2½ minutes after the exposure The post-exposure threshold at 6 minutes after the exposure was defined as the average of the ten measurements of the threshold obtained between 3¾ and 8¼ minutes after the cessation of the noise Likewise, the post--exposure threshold at 11 minutes was defined as the average of the ten measurements of the threshold in the interval 8¾ to 13¾ minutes after the exposure

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*This paper is part of a thesis submitted in partial fulfillment of the requirements for the Doctor of Philosophy degree in the Department of Psychology Indiana University The research was supported in part by the United States Air Force under Contract No AF 18(600)-571 monitored by the Operational Applications Laboratory Air Research and Development Command Bolling Air Force Base, Washington 25 D C This is Report No AFCRC-TN-56-70 ASTIA Document No AD-110052

For each listener, THLs were computed for the different times after exposure by subtracting the pre-exposure threshold from the post-exposure thresholds just defined

In order to detect and to avoid any cumulative auditory effects of this series of exposures, the following precautions were taken For a given listener, successive sessions were separated by at least 48 hours Audiograms (500-8000 c p s ) were taken at the beginning of each session If these thresholds were not within six db of their values at the previous session, then the session was terminated, and the exposure was delayed 24 hours

### RESULTS

To check on the possibility that there were effects due to either practice or the repeated exposures to noise, the pre-exposure thresholds for the individual listeners were plotted against sessions No consistent trends appeared in these curves Also, the mean THLs for Session II to VII were examined In each of these means, the six listeners and the six intensities (90-115 db ) were represented, since over this portion of the experiment noise intensities and sessions were counterbalanced over listeners No trends toward greater or smaller THLs were noted, thus, there was no evidence for changes in THLs due to practice or to the repeated exposures to noise levels are estimates of the SPL under the cushion The level in a 6-cc coupler would be about 8 db greater Each listener was exposed at each of these eight levels The intensity of the noise was 85 db at the first session and 120 db at the last session The intermediate noise levels were assigned to listeners and sessions by means of a 6x6 latin square which was selected randomly, thus, for Session II to VII and for noise intensities 90 to 115 db, the effects of sessions and intensities were counterbalanced

The threshold measurements were obtained by the method of adjustment The listener controlled the intensity of the tone by means of an attenuator which had a range of 60 db with steps of two decibels, he was instructed to bracket his threshold by manual adjustment of the attenuator A test tone was presented for a 15-second period By this method the listener was allowed 15 seconds to adjust the tone to his threshold At the end of the 15-second period, he reported the attenuator reading at which he could just detect the tone When repeated measurements were obtained, there was a 15-second period of silence between the successive measurments

The test tone was interrupted once per second by an electronic switch It was on for 7 seconds and off for 3 seconds The rise-fall time was 50 milliseconds Another attenuator was in tandem with the one that the listener manipulated From trial to trial the experimenter haphazardly varied the amount of attenuation in the second pad This was done so that the listener would not be influenced by his settings on previous trials

Temporary hearing loss (THL) is defined as the difference in decibels between the pre-exposure threshold and the post-exposure threshold The pre-exposure threshold was defined for each listener as the mean of five determinations of the threshold which were obtained immediately before each exposure It was desirable to obtain the most reliable measure of the THL produced by each intensity of the noise after various periods of recovery For this purpose the following variables were defined for each listener at each session The post-exposure threshold at 15-seconds after the cessation of cessation of the noise roughly parallel the THLs 15 seconds after the exposure. Although not shown in Fig. 1, the curves for the THLs 2½ minutes and 11 minutes after the exposure seem to fit into the family of curves. The mean THL for the different times after exposure is given for each intensity of noise in Table I.

Because of individual differences, the basic relationships among THL, time after exposure, and the intensity of the noise may be distorted by averaging all listeners together. It is important to examine the data for the individual listener, and the data are plotted in this way in Fig. 2.

TABLE I

THE MEAN THL AT 4000 C.P.S. FOR DIFFERENT TIMES AFTER THE EXPOSURE AND EACH OVERALL INTENSITY OF THE NOISE

| Time After Exposure | INTENSITY OF THE NOISE<br>85 | 90 | 95 | 100 | 105 | 110 | 115 | 120 |
|---|---|---|---|---|---|---|---|---|
| 15 seconds | 4.0 | 4.4 | 9.3 | 14.5 | 23.7 | 28.5 | 38.3 | 46.2 |
| 1 minute | .6 | 1.8 | 3.7 | 9.8 | 14.5 | 17.9 | 26.0 | 27.5 |
| 2½ minutes | 2.2 | 3.3 | 5.3 | 9.0 | 13.0 | 15.6 | 21.0 | 22.1 |
| 6 minutes | 1.1 | 1.6 | 3.2 | 6.6 | 9.8 | 13.0 | 17.3 | 15.2 |
| 11 minutes | 1.1 | 1.3 | 2.6 | 5.9 | 8.4 | 11.9 | 14.5 | 12.7 |

Consider the data for JF shown in panel A. The THLs determined 15 seconds, 1 minute, and 6 minutes after the exposure are shown by the open circles, the filled circles, and the squares respectively. Over their early portions these curves are positively accelerated, and then they become almost linear. That is, once THL has become as large as 15 or 20 db., the remaining portion of the curve can be approximated by a straight line with a slope of about two.

The curves for the other listeners show either an inversion or a leveling off when the highest intensities are reached. This fact will be discussed later. For the present purposes, only the data up to a point of the inversion or leveling off will be considered. This is done by finding for each listener the noise intensity at which the curve in Fig. 2 for THL 6 minutes after the exposure either shows a maximum or levels off. An arrow indicates this intensity for each listener. All THLs for intensities to the right of the arrow are disregarded

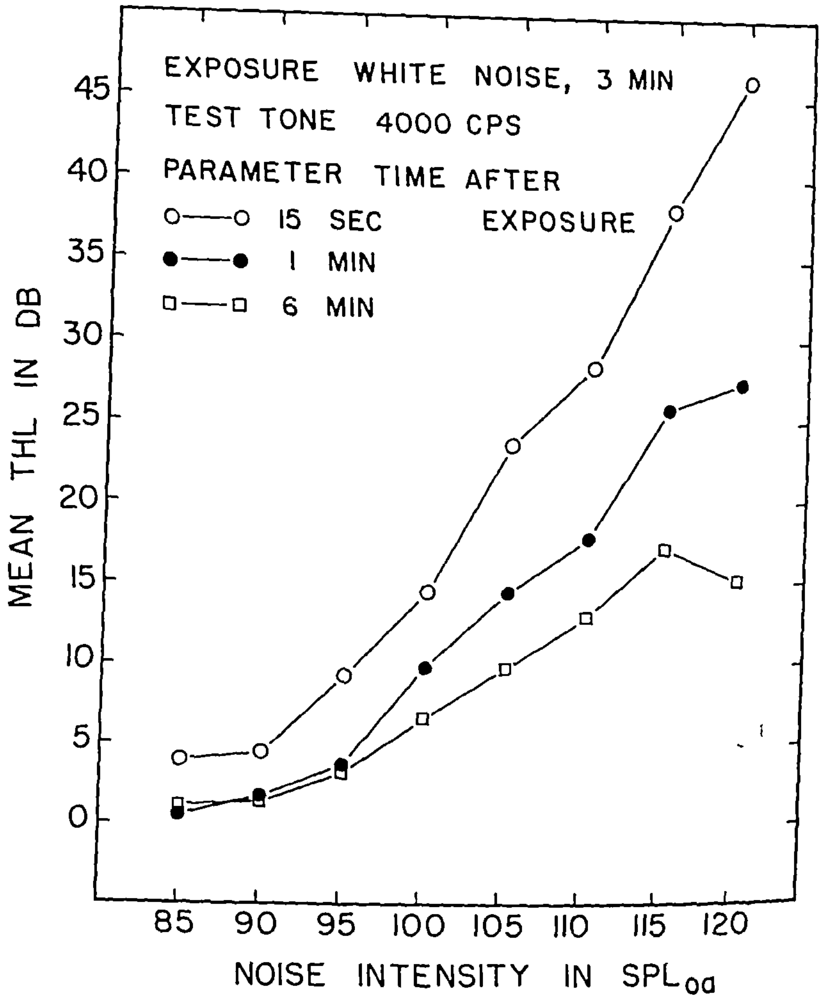

Fig 1 Temporary hearing loss at 4000 c p s as a function of the intensity of a 3-minute exposure to white noise The parameter is the time after the cessation of the noise Each point is the mean of the results for six listeners

A plot of THL against the intensity of the noise is shown in Fig 1 Each point is a mean based upon the results from the six listeners The parameter is time after exposure The curve for the THLs determined 15 seconds after the exposure is positively accelerated over its early portions, and then it becomes approximately linear with a slope of about one and one-half Except for the exposure to 120 *db*, the curves for the THLs one minute and six minutes after the cessation of the noise roughly parallel the THLs 15 seconds after the exposure. Although not shown in Fig. 1, the curves for the THLs 2½ minutes and 11 minutes after the exposure seem to fit into the family of curves. The mean THL for the different times after exposure is given for each intensity of noise in Table I.

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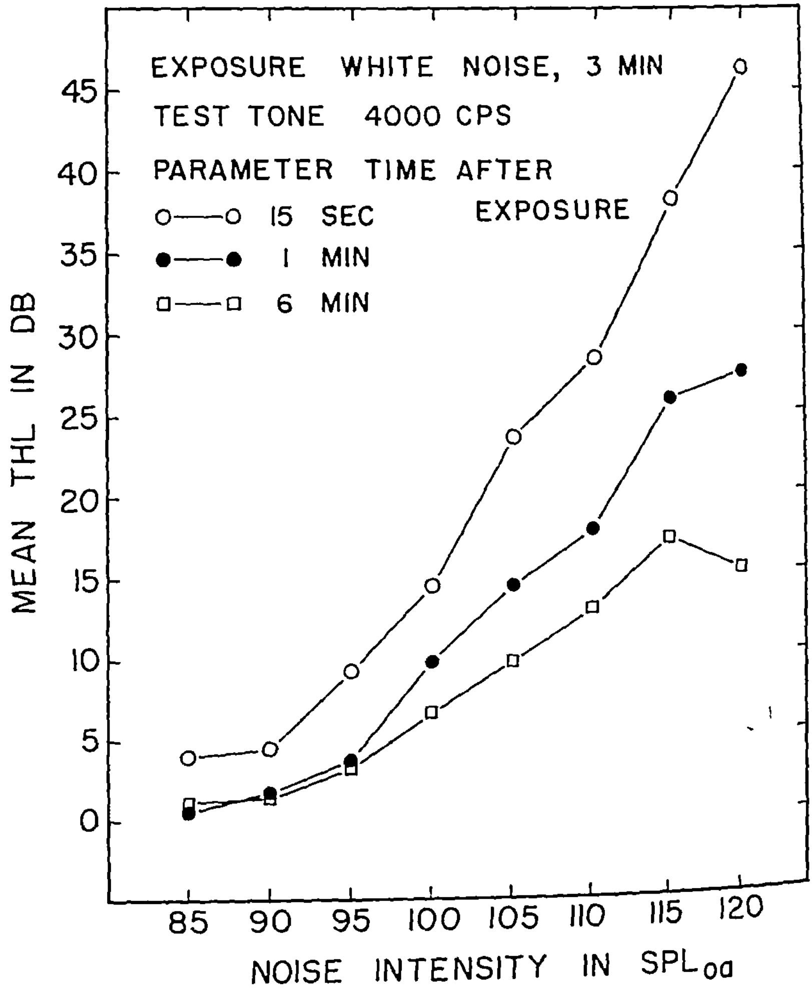

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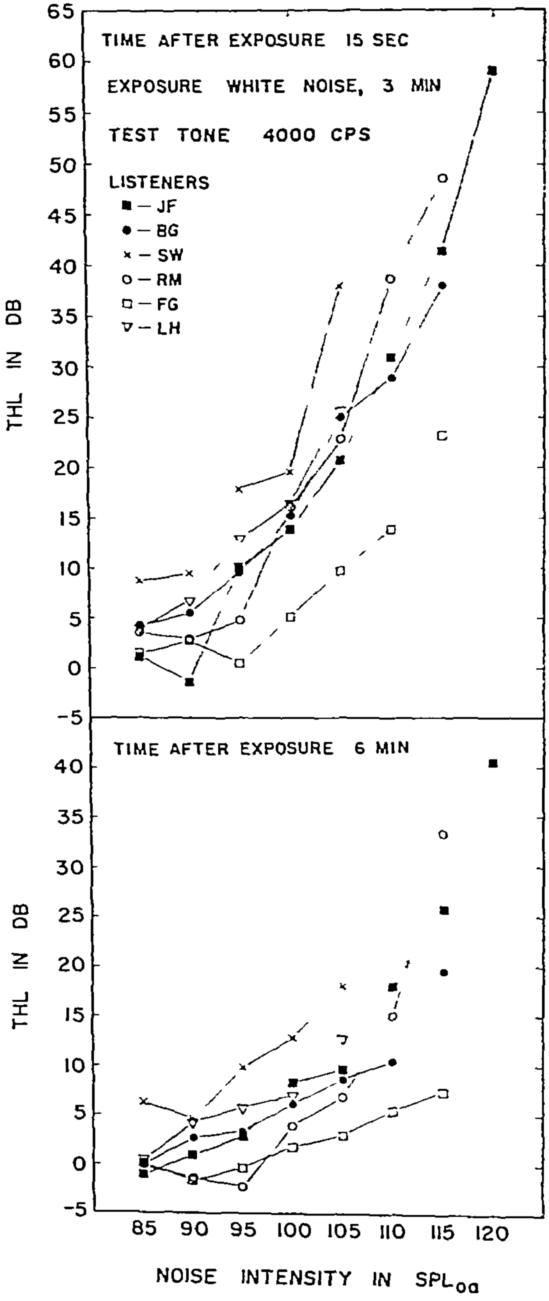

Fig 3 A comparison of the curves for the individual listeners showing THL at 4000 c p s as a function of the intensity of 3 minute exposure to white noise The upper panel shows the THLs at 15 seconds after the cessation of the noise The lower panel shows the THLs at 6 minutes after the cessation of noise These data were taken from Fig 2 but only the data up to the point indicated by the arrow are included See text for explanation

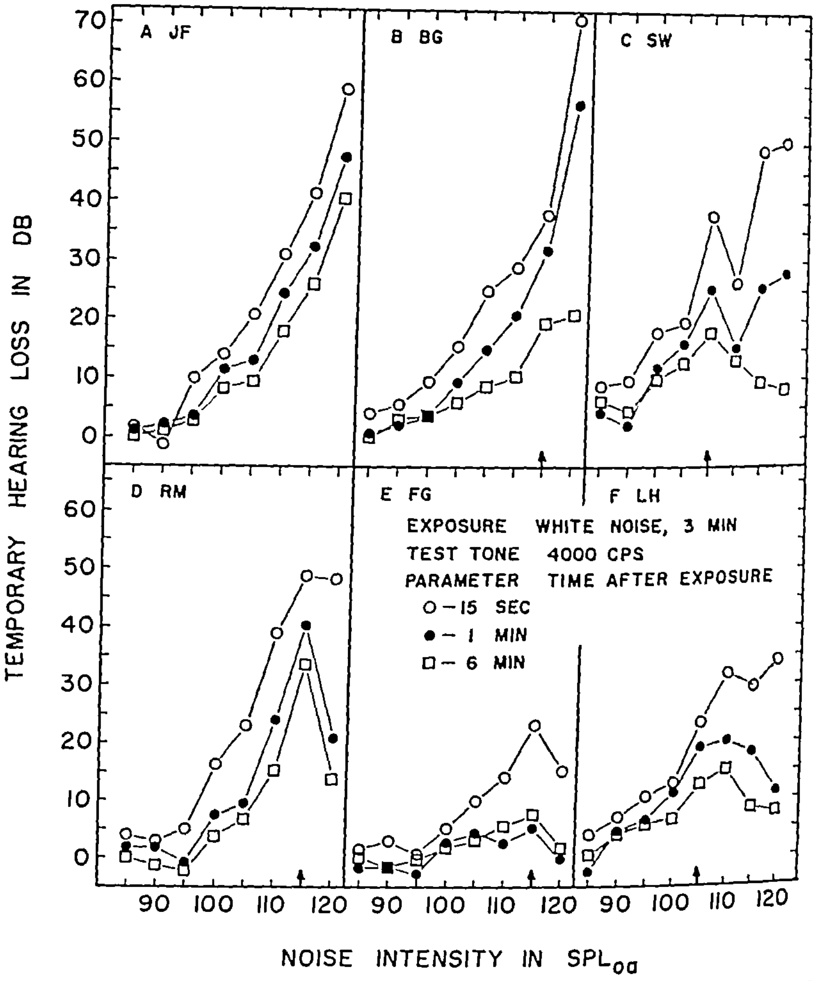

Fig 2 Curves for individual listeners showing THL at 4000 c p s plotted against the intensity of a 3-minute exposure to white noise The parameter is the time after the cessation of the noise The arrow in each panel indicates the intensity above which the 6-minute curve either levels off or declines

Under these conditions, examination of the data shown in Fig 2 suggests that for a given listener the curves for the three different times after the exposure can be superposed by shifting their positions along the intensity axis

In order to facilitate comparisons among the listeners, part of the data of Fig 2 are replotted in Fig 3 The upper panel shows the THLs 15 seconds after the exposure, and the lower panel shows the THLs 6 minutes after the ex-

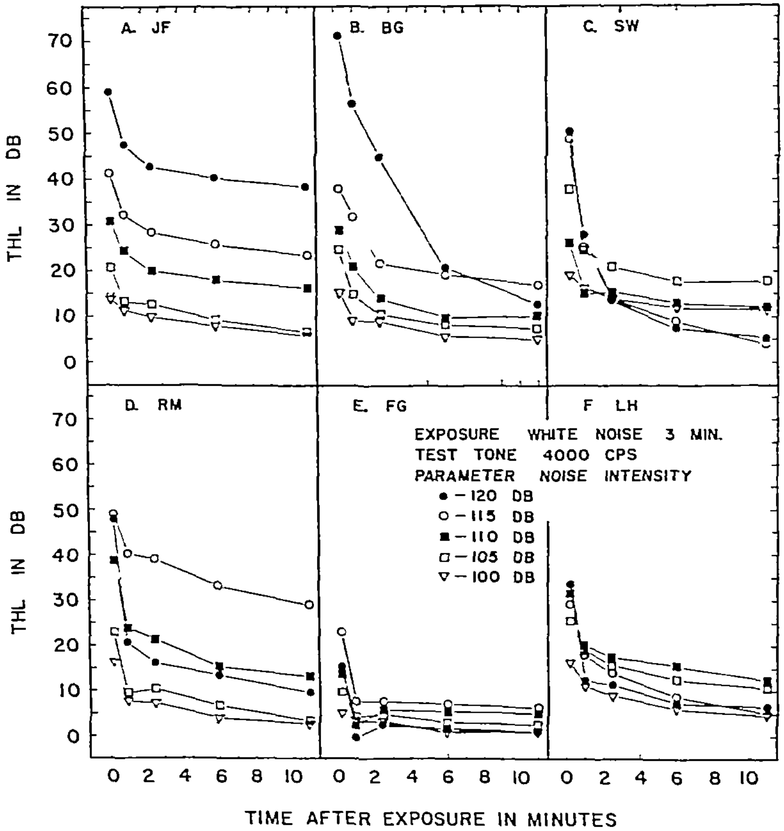

Fig. 4. Recovery of the 4000 c.p.s. threshold after a 3-minute exposure to white noise. Each panel shows the data for an individual listener. The parameter is the over-all intensity of the noise.

covery curves after exposure to the "low" noise intensities are remarkably independent of the noise intensity. Also, listener JF did not show a maximum in his curves for THL plotted against noise intensity (see Fig. 2). The recovery curves for JF in panel A of Fig. 4 all have much the same shape.

The marked change in *rate* of recovery in the results of the experiment reported here cannot be explained readily by assuming that some protective mechanism of the ear simply reduced the effective stimulation of the inner ear during the duration of the exposure. It would seem that such a mechanposure These curves have been "amputated" as suggested in the previous paragraph It can be seen that the shapes of the curves are highly similar for all listeners Inspection of these graphs suggests that the main difference among listeners is the position of the curve along the intensity axis Of course, this conjecture can be correct only for the THLs up to the intensity at which the inversion or leveling off occurs

An inversion or sharp deceleration in curves showing THL as a function of the intensity of the exposure stimulus will now be discussed With an exposure stimulus of about 120 db, Egan,[4] using white noise, and Davis, et al,[2 3] using pure tones, also found this effect Davis, et al, add that the intensity at which this "bend-over" occurred varied from listener to listener and for a single listener from day to day These investigators interpreted their results to mean that some protective mechanisms of the ear, such as a contraction of the intra-aural muscles or a change in the mode of vibration of the stapes, attenuates the effective stimulation of the inner ear Referring back to Fig 2 above, if one were to look at only one curve at a time, then the data would fit into the pattern described by Egan and by Davis, et al

The nature of the change that takes place after THL reaches a maximum can be best illustrated by plotting for each listener the family of recovery curves with the intensity of the noise as a parameter Fig 4 shows the data plotted in this way These are essentially the same data as shown in Fig 2, but the data for more times after the exposure and fewer intensities are given

The recovery curves for BG and RM given in panels B and D show an effect present in the data for all listeners with the exception of JF Recovery from the more intense exposures is so rapid that the recovery curve crosses the recovery curves for the less intense exposures This crossing of recovery curves can be noted also in the data of SW, FG, and LH This change in the rate of recovery is quite dramatic, as can be seen by examining the recovery curves before the "bend-over" is reached The shapes of the re-

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# CLINICAL BONE CONDUCTION AUDIOMETRY AT THE FRONTAL BONE

(Abstract)*

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Our interest in clinical bone conduction audiometry stems directly from early tuning fork days when the value of comparisons between air conduction and bone conduction hearing was very well recognized The level of interest current 50 or more years ago is well illustrated by the fact that at that time Quix was able to quote well over 200 papers concerned with bone conduction hearing, and for the most part our interest has diminished very little since the advent and development of the electrical audiometer Some accept bone conduction audiometric test results at their face value, others emphasize their value and accuracy, and there are a few otologists and audiologists, perhaps the more discriminating, who have no confidence at all in such measurements, and who have little or nothing to do with them

The almost universal practice of carrying out bone conducism would reduce the early THLs as much as the THLs at the later times after the exposure

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*This paper has been published in full in Archives of Otolaryngology 66 281-298 1957

## SUMMARY OF RESULTS

*1* The shape of the curve relating THL to intensity of the exposure stimulus is nearly the same at different times after the cessation of the noise The main effect of time after exposure is to shift the position of the curve along the intensity axis

*2* The shape of the curve relating THL to noise intensity is nearly the same for all listeners The main difference among listeners appears to be the position of the curve along the intensity axis

*3* For THL >15 db, the relationship between THL and noise intensity for the individual listener can be approximated by a straight line with a slope of about two

The above conclusions are qualified by the fact that a leveling off or maximum in the curves relating THL to noise intensity occurs for most listeners, once the noise intensity becomes as great as 110-120 db Individuals appear to differ with regard to the intensity at which this effect first occurs

With regard to individual differences in susceptibility to temporary hearing loss, the following hypothesis is tentatively proposed A given listener's position in a frequency distribution of THLs, when all listeners are exposed and tested under the same conditions, will depend upon two factors *1* the position of his curve (THL against noise intensity) along the intensity axis, and *2* the intensity at which this curve shows a leveling off or an inversion

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use of both air conduction and bone conduction receivers on the same ear

Other observations by Barany led to the conclusion that we may do better in clinical bone conduction tests if we place the bone conduction receiver on the frontal bone, inertia and cartilage conduction would thus be reduced or abolished, there would probably be less inter-subject variation in bony contour, and it is far simpler to apply a bone conduction receiver to the frontal bone than to the mastoid, and far easier to be sure of reproducing the test conditions as tests are repeated One distinct advantage of the frontal bone site is the ever-present reminder that the ears are being stimulated equally, and that masking is almost always required, moreover, while using a frontal bone conduction receiver the two ears may be covered by air conduction receivers, and masking tones may very conveniently be fed to either ear at will

One minor and readily overcome disadvantage of the frontal site is that at most test tone frequencies more power is required to reach the threshold of hearing than is required at the mastoid bone

The importance of the size of the frontal sinuses in bone conduction measurements of this type remains an uncertain quantity, but it is one that must be examined further

If we are to consider seriously the possibility of making bone conduction measurements at the frontal bone while our listeners wear a pair of air conduction receivers, we must learn a good deal more than is generally known at present concerning the occlusion effect in pathological ears We must in particular know whether cases with pathological hearing will show occlusion effects resembling those shown by the normal ear Such evidence as there is, suggests that the normal occlusion effect will be reduced in the case with a pathological middle ear by an amount equal to the magnitude of that ear's conduction deafness

In an attempt to gain further information on this and other related problems, about 500 ears were tested, audiometrically, some had visible middle ear changes of various types, some had otosclerosis, and some had neither visible changes nor tion tests with the receiver applied to the mastoid process of the tested ear is perhaps unfortunate, because it encourages the false notion that the opposite or untested ear remains in splendid isolation, separated from the test tone just as effectively as is recognized to be the case in air conduction tests, however, the inadequacy of bone conduction isolation has now been accepted, and the resulting and almost invariable need for masking is well recognized, but we still adhere to the mastoid process, a site with very little to recommend it

Barany, many years ago suggested, with clearly stated reasoning, that the mastoid process was far from being the best site of application for the bone conduction receiver in clinical tests All of our present measures of bone conduction hearing are confused to some extent by reflections of middle ear function, an inevitable result of inertia bone conduction hearing and other factors, of all the possible sites available for a bone conductor receiver, the mastoid process will give us the greatest confusion, because at this site inertia bone conduction is at a maximum Barany also pointed out that clinical bone conduction hearing will increase as the receiver is moved closer to or into contact with the cartilage of the external ear, another argument against the adequacy of the mastoid site There are numerous other disadvantages entailed in using the mastoid process, mastoids vary widely in tissue density and "the most sensitive spot of the mastoid" varies in position from individual to individual Otologists who have carried out bone conduction tests will agree that it is often impossible, using a double headset with an air conduction and a bone conduction receiver, to persuade the bone conduction vibrator to do more than perch precariously behind the listener's ear, and the choice of application site disappears when the receiver can be made to stay on the head in only one position Another difficulty encountered is reproduction of original test conditions, in terms of application site and pressure, as tests are repeated from time to time A final objection to the mastoid type of bone conduction test is that the tested ear must remain exposed to any air-borne ambient noise during the test, because our orthodox air conduction receivers are too large to permit the simultaneous

The points mentioned lead to the conclusion that clinical bone conduction audiometry, carried out with occluded ears and with a frontal bone conduction receiver, is well worth serious consideration Our orthodox techniques resemble efforts to compare the weights of a number of men, any of whom may be concealing 15 db of lead about their persons Occluded frontal bone tests will ensure that, whether "built-in occlusion effect" is present or absent, we derive a far less inaccurate measure of cochlear reserve

The observations described were made in the course of a series of small scale probes into the question of clinical bone conduction hearing The results suggest that well planned attacks on the problem are likely to be rewarding

# PROPOSED AUDIOLOGY CENTRE OF THE NATIONAL CENTRE FOR THE DEAF IN INDIA

(Abstract)

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and
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For the past few years it has been the earnest endeavor of the Government of India of finding ways and means to quicken the pace of rehabilitation of the handicapped persons With this object in view, the Committee on Deafness was appointed in 1952, and the Deaf Seminar held in September, 1955, which was ably presided by Shri U A Basrurkar

Dr C A Amesur, who has published a paper on "Lip Reading" in I J O, October, 1950, and "Rehabilitation of the acoustically handicapped" in the I J O, December, 1952, was requested by the Ministry of Education to give a talk on "Recent Progress in the Treatment and Prevention of Ear otosclerosis. A frontally applied bone conduction receiver was used throughout, and all the cases were tested in each of two ways: first, bone conduction with unoccluded or open ears, and second, bone conduction while the ears were occluded with a pair of standard air conduction receivers. Masking was used in adequate amount to separate the function of the two ears. The differences between the unoccluded and the occluded bone conduction thresholds were accepted as occlusion effects, and it became clear that most of the cases with normal middle ears, whether deaf or otherwise, showed the expected occlusion effect of about 15 db. at 250 and 500 c/s, a lesser occlusion effect at 1000 c/s, and no occlusion effect at 2000 and 4000 c/s.

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It also became clear that the majority of the cases with middle ear changes showed no occlusion effects at *any* test tone frequency, irrespective of the size of the air conduction loss present. One further observation was that at some test tone frequencies the cases with middle ear lesions and moderate air conduction hearing losses showed bone conduction thresholds better, on the average, than the unoccluded normal ears' thresholds. In other words these observations demonstrated the presence, in cases of mild middle ear deafness, of what has been referred to for very many years as "prolonged bone conduction hearing." It should be added that the phenomenon has often been referred to as "the *illusion* of prolonged bone conduction."

It has been pointed out above that the cases with moderate middle ear deafness had better than normal bone conduction hearing, and that these same cases will show no further improvement in bone conduction hearing when their ears are occluded, but the normal ear's bone conduction hearing will improve when the ear is occluded and comes up to the level of the pathological cases with "prolonged bone conduction." There is, therefore, some justification for stating that the pathological middle ears are behaving as though they were in a permanently occluded state, a state the author has tentatively labelled "built-in-occlusion." This may be a misleading term, and comments must be limited to the observations that the effects are very similar in terms of frequency distribution and of magnitude.

false security In Denmark the purchase of hearing aids is based on tenders in order to stimulate competition The individual hearing aids are controlled by an "artificial ear" at the Hearing Center, the plotted frequency curves are filed, and the individual hearing aids registered on index cards so as to have detailed account of the commonest defects Based on this file of defects, standards are prepared for improvements in new types of hearing aids The fitting of the hearing aid is based on a close cooperation between engineers and physicians

The capricious problem in the matter of fitting hearing aids is training in the use of the apparatus It is of the greatest importance that the patients persevere for the first month until they have adapted themselves to the aid and its secondary noises All the patients are referred to courses of up to four hours' instruction, and more than 50 per cent of the patients are trained in lipreading, hearing training, and speech correction Through reports of the 63 teachers of patients with defective hearing, operating in the area of the Hearing Centers, we are able to check the correctness of the rehabilitation process Particularly difficult cases are referred, and admitted to the college for hard-of-hearing adults at Fredericia, a rather unique institution, unknown in most other countries The training of children is supervised by traveling teachers who visit the individual homes of the children about eight times a year When necessary, vocational guidance is instituted

A re-examination of the first 8,000 patients of the Hearing Center in Copenhagen showed that only 4 per cent of the patients failed to use their hearing aids The re-examination was based on questionnaires, inquiries of personal friends, and reports from the teachers The small figure should hence be considered reliable, and be taken as an indication of the method applied by the Hearing Center, and classification of the patients Seventeen per cent of the applicants are not provided with hearing aids, either because their deficiency is not sufficiently pronounced or because they suffer from types of defective hearing which are not remedied by hearing

Diseases" at the Deaf Seminar, published in I J O, December, 1955 The Seminar accepted his following resolutions

*1* That a model Audiology Centre be set up by the Government of India,

*2* That smaller audiological units should be attached to all teaching hospitals,

*3* That rehabilitation of laryngectomized patients be undertaken

On October 5, 1955, Government of India established the National Advisory Council for the Education of the Handicapped (Resolution No F, 1-34-55, D-2, dated January 9, 1955), and nominated the author on that body

The Council, at its first meeting, held in October, 1955, in the Council Hall of the Lok Sabha, elected the author on its Standing Committee

The Co-author worked out the cost of such a centre, which the author placed before the Council, which accepted the same, on the following day The cost of construction and an appropriate annual budget will be discussed

The authors acknowledge their debt to many colleagues in Europe, the United Kingdom and the United States

### DISCUSSION

H W EWERTSEN, Copenhagen, Denmark In Denmark we now have six years' experience with the State Hearing Rehabilitation Centres, of which there are three, in cooperation with a special children's clinic Every Danish inhabitant, with hearing troubles of chronic character, is allowed free admission to the rehabilitation program, including examination by otologist, acoustic evaluation by pure tone and speech audiometry, fitting of hearing aids, vocational guidance, teaching and follow-up

The experience of the Copenhagen Hearing Center shows beyond doubt the necessity of a current control of all hearing aids supplied to patients Official authorization based on a few selected specimens proved quite inadequate, providing a

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aids Persons, who on account of mental insufficiency are unable to manage the hearing aid, are not supplied

As compared with all other medical care, the audiological rehabilitation of the hard-of-hearing persons must be considered an inexpensive and efficient measure, which often totally changes the entire outlook on life of the patient

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Arthur L. Holcomb Los Angeles Calif
W H Hopmeier St. Louis Mo
L LeRoy Horne Wilmington, Dela.
Clarence V Hudgins Northampton Mass
Robert J Hunter Philadelphia Pa
Lloyd A Jeffress Austin Texas
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E W Johnson Los Angeles Calif
Kenneth O Johnson San Francisco Calif
Maurice Joseph New Orleans La.
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Jacqueline Keaster Los Angeles Calif
John W Keys Norman Okla.
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Hayes A. Newby Palo Alto Calif
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Samuel Rosen New York, N Y
Philip E Rosenberg Philadelphia Pa.
H. Rosenberger Cleveland, O
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Minoru Muta, Osaka
Fumio Nakamura Kyoto

## MALTA

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## MEXICO

Pedro Berruecos, Mexico City

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J J Groen, Utrecht
H A E van Dishoeck Leyden
Henk C Huizing, Groningen

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Ernesto Raffo, Lima

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Jon Miodonski, Krakow
Jerzy Szpunar Krakow
Josef Taniewski Stettin

## PUERTO RICO

M Alonso Santurce
Juan H Font, San Juan

## SWEDEN

Lennart Gisselsson Lund
Y Jungert, Stockholm

## SWITZERLAND

Franz Escher Berne

## VENEZUELA

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Mrs Tina Bangs Houston Texas
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Willem A van Bergeijk Murray Hill N J

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Joseph A Butler, Chicago Ill
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Norton Canfield, New Haven, Conn
Raymond Carhart, Evanston, Ill
Claire Cooper Nashville Tenn
Mary R Costello Detroit Mich
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Walter P Covell, St Louis, Mo
J R Cox, Jr, St Louis Mo
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Catherine Lee Cubert, Chicago, Ill
Harold Cutler St Louis, Mo
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K M Day Pittsburgh Pa
Bruce Deatherage St Louis Mo
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Leo G Doerfler Pittsburgh Pa
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John H Gaeth Detroit, Mich
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Harry N Glick St Louis, Mo
Aram Glorig Los Angeles Calif
Cornelius P Goetzinger Kansas City, Kans
Robert Goldstein St Louis Mo
Victor Goodhill Los Angeles Calif
Allan Goodman St. Louis Mo
A. Bruce Graham, Detroit Mich
Rufus L Grason West Concord Mass

# PROGRAM OF THE AMERICAN OTOLOGICAL SOCIETY, INC

Fairmont Hotel, San Francisco, Calif, May 17-18, 1958

*Anatomical Structure of the Stapes and the Relation of the Stapedial Footplate to Vital Parts of the Otic Labyrinth*
Barry J Anson, M D, and Theodore H Bast, M D

*Repair and Consequences of Trauma to the Stapes and Oval Window in Experimental Animals*
Richard J Bellucci, M D, and Dorothy Wolff, M D

*The Action of the Sense Organ of the Cochlea, Particularly from the Point of View of Neurophysiology and the Excitation of Nerve Impulses*——Hallowell Davis, M D

*Observations on Temporary Threshold Shift Resulting from Noise Exposure*——Aram Glorig, M D

*Congenital Stapes Fixation*——Howard House, M D

*Physiological Mechanisms in Stimulation Deafness*
Merle Lawrence, M D

No Subject Assigned——John R Lindsay, M D

*Portmortem Findings in Temporal Bones of Animals and Humans*——H F Schuknecht, M D

*Studies Concerned with Tubo-tympanitis*
Ben Senturia, M D

*Neurological Survey of the Children at Central Institute for the Deaf and Analyzed Results in Relation to Their Audiograms, Their Educational Advancement, Their Social Adjustment, etc*
R S Silverman, Ph D, and Hallowell Davis, M D

*A Study of Destructive Labyrinthotomy*
K M Simonton, M D

*Further Studies on the Function of the Utricular Macula*
J A. Sullivan, M D, Walter Johnson, M D,
and Brydon Smith, M D

## UNITED STATES

Harold F Schuknecht, Detroit, Mich
Martin C Schultz, Philadelphia, Pa.
Lewis J Schwartzkopf, Columbus, O
Barbara J Seelye, St Louis, Mo
Ben H Senturia, St Louis, Mo
James L Shapley, Iowa City, Iowa
Andrew J Shiner, Falls Church, Va
Irvin Shore, St Louis, Mo
Bruce M Siegenthaler, University Park, Pa
S Richard Silverman, St Louis Mo
A A Simmons, St Louis, Mo
Sister Anna Bernadine, St Louis Mo
Sister Anna Rose, St Louis, Mo
Sister Rose Antonia, St Louis, Mo
Catherine A Smith, St Louis, Mo
Francis L Sonday, Indianapolis, Ind
M Spencer, St Louis, Mo
Isabelle Starkey, Lansing, Mich
Clayton Stevens LaPuente, Calif
S S Stevens, Cambridge, Mass
Agnes A Stokoe Detroit, Mich

## UNITED STATES

Alice Streng Milwaukee, Wis
Ichiji Tasaki, Bethesda, Md
Glenn Taylor, Normal, Ill
Don C Teas, Des Moines Iowa
Alfred R Thea, Kalamazoo, Mich
Nicholas Torok, Chicago, Ill
Archie R Tunturi, Portland, Ore
J Richardson Usher, St Louis Mo
John A Virant, St Louis, Mo
Theo E Walsh, St Louis Mo
W Dixon Ward Pensacola, Fla.
L A Watson, Minneapolis, Minn
Harold Weber, Denver, Colo
John C Webster San Diego Calif
Charlotte G Wells, Columbia Mo
Ruedi Werth New York N Y
Edgar D Wipperman, Covington, Ky
Frank B Withrow St Louis Mo
Mrs Margaret Withrow, St Louis Mo
Doris Surles Woolsey, St. Louis, Mo
Donald M Wright, Quincy Ill
Herbert N Wright, Chicago, Ill
Norman E Wynn, Chicago, Ill
Phillip A Yantis, Ann Arbor Mich
Josef Zwislocki, Cambridge, Mass

*Film Recording of Esophageal Speech by Means of the Image Intensifier*
Medical Division, North American Phillips Co , Inc

*Technical and Electronic Field*
Speaker from the Bell Telephone Laboratories

*New Operation for Short Circuiting the Tracheal Air into the Pharynx*....John J Conley, M D

Tuesday, May 20, 1958

*Changing Trends in the Treatment of Sinusitis*
Frederick T Hill, M D

*Nasal Obstruction Produced by Deformities about the Lobule*....Henry L Williams, M D

*Carcinoma-in-situ of the Larynx a Ten-Year Study of its Histopathological Classification, Prognosis and Treatment*....Alden H Miller, M D
and Russel Fisher, M D (By Invitation)

*Bronchoscopic Findings in Tubercular Children*
D E S Wishart, M D ,
and J B Whaley, M D (By invitation)

PRESENTATION OF INSTRUMENTS

*Unusual Sinuses*....Fred W Dixon, M D

*Orbital Apex Syndrome*....Austin T Smith, M D

*Physiology of the Larynx Under Daily Stress (Film)*
Paul G Moore, M D (By invitation),
and Hans von Leden, M D (By invitation)

*The Experimental Use of Homografts for Repair of the Cervical Trachea*....Joel J Pressman, M D

*The Origin of Distortion in Cochlear Fluid Motion*
J Tonndorf, M D

*Pressures of the Labyrinthine Fluids Measured with an Electromanometer and Potential Value of These Pressures*
Francis L Weille, M D , and John Irwin, M D

*The Differential Diagnosis of Meniere's Disease*
Henry Williams, M D

## PROGRAM OF THE AMERICAN LARYNGOLOGICAL ASSOCIATION

Fairmont Hotel, San Francisco, Calif , May 19-20, 1958

*Ground Substance* ........Eugene S Hopp, M D (By invitation)

*Vocal Rest in Laryngeal Disease*..... ..Melvin C Myerson, M D

*Management of Chronic Laryngeal Stenosis*
Paul H Holinger, M D

*Evidence of Laryngeal Participation in Emotional Expression Its Relation to Hysterical Aphonia.*
A C Furstenberg, M D

### EXECUTIVE SESSION

Panel Discussion

### AFTERNOON SESSION

REHABILITATION OF THE POST-LARYNGECTOMIZED PATIENT
John J Conley, M D , Moderator

*Types of Clinical Cases and Their Resultant Laryngeal, Esophageal, Pharyngeal and Neck Deformities*
Charles M Norris, M D

*The Vocal Therapist Place and Contribution to the Rehabilitation Program*........Paul J Moses, M D (By invitation)

*Specific Discussion of Failures Advanced and Difficult Technical Problems* ........ ................. . ....... .....F Johnson Putney, M D

*Psychological Factors Determining the Success or Failure of the Rehabilitation Program*
Hayes A Newby, Ph D (By invitation)

SYMPOSIUM—*Modern Criteria for Diagnosis and Therapy of Malignant Disease in the Upper Respiratory Tract*

Moderator ........ Jerome A Hilger, M D , St Paul, Minn

Panel ........ Harold G Tabb, M D , New Orleans, La
Walter P Work, M D , San Francisco, Calif
John J Conley, M D , New York, N Y

*Combined Laryngectomy and Neck Dissection (A Motion Picture)* ........ Eugene L Grandon, M D , Iowa City, Ia
(By invitation)
Edgar S Brintwall, M D , Iowa City, Ia
(By invitation)

*An Objective Approach to the Complaint "A Lump in the Throat"* ........ G Arnold Henry, M D , Toronto, Canada

Friday, May 23, 1958

*A Clinical Look at Progress in the Evaluation of Hearing Function* ........ Frederick R Guilford, M D , Houston, Texas

*An Unusual Paratoid Swelling—Its Diagnosis and Treatment*
Albert C Furstenberg, M D , Ann Arbor, Mich

*The Motor Activity of the Cricopharyngeus Muscle—A Laboratory Study (Candidate's Thesis)*
John A Kirchner, M D , New Haven, Conn

SYMPOSIUM—*Stapes Mobilization—Two Years Later*

Moderator ........ Howard P House, M D , Los Angeles, Calif

Panel ........ Merle Lawrence, Ph D , Ann Arbor, Mich
Philip E Meltzer, M D , Boston, Mass
John R Lindsay, M D , Chicago, Ill
Victor Goodhill, M D , Los Angeles, Calif
Samuel Rosen, M D , New York, N Y
Clair M Kos, M D , Iowa City, Ia
George E Shambaugh, M D , Chicago, Ill
Edmund P Fowler, Jr , M D , New York, N Y

# PROGRAM OF THE AMERICAN LARYNGOLOGICAL, RHINOLOGICAL AND OTOLOGICAL SOCIETY, INC

## Wednesday, May 21, 1958

*The Relationship of Thyroid Carcinoma in Children and Irradiation of the Thymus in Infancy*
Shirley H Baron, M D , San Francisco, Calif

Discussion ...Robert R Newell, M D , San Francisco, Calif
(By invitation)

*Middle Ear Effusion—Systemic Factors*
Francis W Davison, M D , Danville, Pa

Open Discussion

SYMPOSIUM—*Reconstructive Nasal Surgery*

Moderator...... .....Ronald W Taylor, M D , Vancouver, B C

Panel........ .. .........Russell I Williams, M D , Cheyenne, Wyo
Joseph H Ogura, M D , St Louis, Mo
Harold Owens, M D , Los Angeles, Calif

*The Transseptal Intra-Nasal Dacryocystorhinostomy—A Neglected Operation (A Motion Picture)*
E R V Anderson, M D , Los Angeles, Calif

*Malformations and Anatomical Variations Seen in the Middle Ear During the Operation for Mobilization of the Stapes (Candidate's Thesis)*
Jack V Hough, M D , Oklahoma City, Okla

## Thursday, May 22, 1958

*Soft Tissue Roentgenography of the Nasopharynx for Adenoids*.............Joseph L Goodman, M D , New York, N Y

Open Discussion

*An Operative Technique to Prevent the Need of Postoperative Care in Radical Mastoid Surgery*
J H Thomas Rambo, M D , New York, N Y

Open Discussion

### AMERICAN OTOLOGICAL SOCIETY, INC

President Dr Dean M Lierle, State University of Iowa, Iowa City, Ia.
Secretary Dr Lawrence R Boies University Hospitals, Minneapolis 14, Minn
Place Fairmont Hotel San Francisco, Calif, May 17 18, 1958
Place The Homestead Hot Springs, Va, 1959

### AMERICAN OTORHINOLOGIC SOCIETY FOR THE ADVANCEMENT OF PLASTIC AND RECONSTRUCTIVE SURGERY

President Dr Joseph Gilbert, 111 E 61st St., New York, N Y
Vice-President Dr Kenneth Hinderer, 402 Medical Arts Bldg, Pittsburgh Pa.
Secretary Dr Louis Joel Feit, 66 Park Ave., New York 16, N Y
Treasurer Dr Arnold L Caron, 36 Pleasant St., Worchester Mass

### AMERICAN RHINOLOGIC SOCIETY

President Dr Russell L Williams 408 Hynds Bldg Cheyenne Wyo
Secretary Dr Robert M Hansen 1735 No Wheeler Ave, Portland Ore
Annual Clinical Session Illinois Masonic Hospital Chicago Ill, October 1958
Annual Meeting October, 1958 Chicago, Ill (Definite time and place to be announced later)

### AMERICAN SOCIETY OF FACIAL PLASTIC SURGERY

President Dr Trent W Smith 327 East State St. Columbus 15 Ohio
Secretary Dr Samuel M Bloom 123 East 83 St. New York 28 N Y
Meeting New York July 23 1958 December 3 1958 place to be announced

### AMERICAN SOCIETY OF OPHTHALMOLOGIC AND OTOLARYNGOLOGIC ALLERGY

President Dr Joseph W Hampsey Grant Bldg, Pittsburgh 19 Pa.
Secretary Treasurer Dr Daniel S DeStio 121 S Highland Ave Pittsburgh 6 Pa.
Annual Meeting Palmer House, Chicago, Ill October 16 17 1958

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Librarian Treasurer Dr Souza Queiroz
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Meetings Twice every month, first and third Thursday, 8 30 P M

### ASOCIACION DE OTORRINOLARINGOLOGIA Y BRONCOESOFAGOLOGIA DE GUATEMALA.

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First Vice-Presidente Dr Héctor Cruz, 3a Avenida Sur No 72
Second Vice-Presidente Dr José Luis Escamilla, 5a Calle Poniente No 48
Secretario-Tesorero Dr Horace Polanco 13 Calle Poniente No 9-D

### ASOCIACION DE OTO RINO-LARINGOLOGIA DE BARCELONA, SPAIN

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Vice-Secretario Dr A. Pinart.
Vocal Dr J M Ferrando

# DIRECTORY OF OTOLARYNGOLOGIC SOCIETIES

(Secretaries of the various societies are requested to keep this information up to date)

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## AMERICAN ACADEMY OF OPHTHALMOLOGY AND OTOLARYNGOLOGY

President Dr Erling W Hansen, 90 So Ninth St., Minneapolis, Minn
Executive Secretary Dr William L Benedict, Mayo Clinic, Rochester, Minn
Meeting Palmer House, Chicago, Ill

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Meeting Palmer House, Chicago, Ill

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Vice-President Dr Walter P Work, 384 Post St., San Francisco, Calif
Secretary Dr F Johnson Putney, 1719 Rittenhouse Square, Philadelphia, Pa
Treasurer Dr Verling K Hart, 106 W 7th St., Charlotte, N C
Meeting Mark Hopkins Hotel, San Francisco, Calif, May 21 23, 1958

## AMERICAN LARYNGOLOGICAL ASSOCIATION

President Dr Harry P Schenk, 326 S 19th St, Philadelphia 3, Pa
Secretary Dr James H Maxwell, University Hospital, Ann Arbor, Mich
Place Fairmont Hotel, San Francisco, Calif, May 19 20, 1958

## AMERICAN LARYNGOLOGICAL, RHINOLOGICAL AND OTOLOGICAL SOCIETY, INC

President Dr Lawrence R Boies, University Hospital, Minneapolis 14, Minn
Secretary Dr C Stewart Nash, 700 Medical Arts Bldg, Rochester 7, N Y
Place Mark Hopkins Hotel, San Francisco, Calif, May 21 23, 1958
Place The Homstead, Hot Springs, Va., March, 1959

## AMERICAN MEDICAL ASSOCIATION, SECTION ON LARYNGOLOGY, OTOLOGY AND RHINOLOGY

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Section Delegate Gordon Harkness, M D, Davenport, Iowa.
Alternate Delegate Dean Lierle, M D, Iowa City, Iowa.

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Secretary-Treasurer Dr Hector R. Silva, Calle Arce No 84, San Salvador, El Salvador, Central America.

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President-Elect Dr Jos W Taylor 706 Franklin St., Tampa, Fla.
Secretary-Treasurer Dr Carl S McLemore, 1217 Kuhl Ave , Orlando, Fla.

## FOURTH LATIN AMERICAN CONGRESS OF OTORINOLARINGOLOGIA

President Dr Dario
Secretary
Meeting

## GREATER MIAMI EYE, EAR, NOSE AND THROAT SOCIETY

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President Elect Dr James H Mendel, Jr
Secretary-Treasurer Dr H. Carlton Howard
Meeting quarterly (March May October and December) on the second Thursday of the month 6 30 P M at Urmey Hotel Miami

## INTERNATIONAL BRONCHOESOPHAGOLOGICAL SOCIETY

President Dr Jo Ono Tokyo, Japan
Secretary Dr Chevalier L Jackson 3401 N Broad St. Philadephia 40 Pa U S A.
Meeting Seventh International Congress of Bronchoesophagology, Kyoto Japan September 1958

## KANSAS CITY SOCIETY OF OTOLARYNGOLOGY AND OPHTHALMOLOGY

President Dr Clarence H. Steele
President Elect Dr Dick H. Underwood
Secretary Dr James T Robison 4620 J C Nichols Parkway Kansas City Mo
Meeting Third Thursday of November, January February and April.

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Secretary-Treasurer Dr Max E. Pohlman.
Chairman of Ophthalmology Section Dr Richard Kratz
Secretary of Ophthalmology Section Dr Carrall A. McCoy
Chairman of Otolaryngology Section Dr Howard G Gottschalk.
Secretary of Otolaryngology Section Dr Robert W Godwin.
Place Los Angeles County Medical Association Bldg 1925 Wilshire Blvd Los Angeles Calif.
Time 6 30 P M last Monday of each month from September to June inclusive—Otolaryngology Section 6 30 first Thursday of each month from September to June inclusive—Ophthalmology Section.

## BALTIMORE NOSE AND THROAT SOCIETY

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Pro Secretario Dr J M Tato
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## CANADIAN OTOLARYNGOLOGICAL SOCIETY
## SOCIETE CANADIENNE D'OTOLARYNGOLOGIE

President Dr Robert T Hayes, 42 Cobourg St, St. John, N B
Secretary Dr Donald M McRae, 324 Spring Garden Rd, Halifax, N S
Meeting Nova Scotian Hotel, Halifax, N S, June 9 11, 1958

## CENTRAL ILLINOIS SOCIETY OF OPHTHALMOLOGY AND OTOLARYNGOLOGY

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President-Elect Dr Phil R McGrath, Peoria, Ill.
Secretary-Treasurer Dr Alfred G Schultz, Jacksonville, Ill

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Vice-President Dr Maurice Snitman, 408 So 5th Ave, Maywood, Ill.
Secretary-Treasurer Dr Fletcher Austin, 700 No Michigan Ave, Chicago 11, Ill
Meeting First Monday of each Month, October through May

## CHILEAN SOCIETY OF OTOLARYNGOLOGY

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Vice-President Dr Agustin Estartus
Secretary Dr Marcos Chaimovich S
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Vice-President Dr Hal W Maxwell
Secretary-Treasurer Dr Edward A Newell, 1511 No Beckley, Dallas 8, Tex.

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Secretary of Exterior Dr Aldo G Remorino
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Pro Secretary of the Treasury Dr Jorge Zubizarreta.

## PACIFIC COAST OTO OPHTHALMOLOGICAL SOCIETY

President H Leroy Goss, M D, 620 Cobb Bldg, Seattle 1, Washington
Secretary Treasurer Homer E Smith M.D 508 East South Temple Salt Lake City, Utah.
Meeting

## PAN AMERICAN ASSOCIATION OF OTO RHINO-LARYNGOLOGY AND BRONCHO-ESOPHAGOLOGY

President Dr Jose Gros, Havana, Cuba
Executive Secretary Dr Chevalier L Jackson, 3401 N Broad St., Philadelphia 40 Pa., U S A.
Meeting Sixth Pan American Congress of Oto-Rhino-Laryngology and Broncho-Esophagology
Time and Place Brazil, 1958

## PHILADELPHIA LARYNGOLOGICAL SOCIETY

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Secretary Dr Willard F Goff, 1215 Fourth Ave., Seattle Wash

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Mid-Winter Clinical Convention annually the last two weeks in January at Los Angeles Calif

## SECTION OF OTOLARYNGOLOGY OF THE MEDICAL SOCIETY OF THE DISTRICT OF COLUMBIA

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Vice-Chairman Dr Russell Page.
Secretary Dr James J McFarland.
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Meetings are held the second Tuesday of September November January March and May at 6 30 P.M.
Place Army and Navy Club Washington D C

## LOUISIANA-MISSISSIPPI OPHTHALMOLOGICAL AND OTOLARYNGOLOGICAL SOCIETY

President Dr H K Rouse, 1300 27th Ave, Gulfport, Miss
Vice-President Dr A. J McComiskey, 3420 Prytonia St., New Orleans, La.
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Meeting

## MEMPHIS SOCIETY OF OPHTHALMOLOGY AND OTOLARYNGOLOGY

Chairman Members serve as chairmen in alphabetical order monthly
Secretary-Treasurer Dr Roland H Myers, 1720 Exchange Bldg, Memphis, Tenn.
Assistant Secretary-Treasurer Dr William F Murrah, Jr, Exchange Bldg, Memphis, Tenn
Meeting Second Tuesday in each month at 8 00 p m at Memphis Eye, Nose and Throat Hospital

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Vice-President Dr M Gonzales Ulloa, Mexico, D F
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Vice-President Dr George E Bradord, Winston Salem, N C
Secretary-Treasurer Dr J D Stratton, 1012 Kings Drive, Charlotte 7 N C
Meeting

## NORTH OF ENGLAND OTOLARYNGOLOGICAL SOCIETY

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Secretary and Treasurer Mr R Thomas, 27 High Petergate York, Yorkshire

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Meeting Palmer House, Chicago Ill

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# RHINOPLASTIC APPROACH FOR DERMOID CYSTS OF THE NASAL DORSUM

## Report of Three Cases *

RALPH H RIGGS, M D ,
Shreveport, La

Reports of midline dermoid cysts of the nasal dorsum have appeared sporadically in the American literature since Birkett's report[1] in 1901 Although the condition is not considered rare, fewer than 75 cases have been reported The lesion is generally agreed to be congenital, and its development is explained on an embryologic basis [2-4]

The purpose of this paper is to present the cases of three patients with dermoid cysts of the nasal dorsum, on whom I have operated, and to discuss rhinoplastic procedures that may be helpful in such cases Previously described approaches to this problem include midline incisions,[3-9] horizontal incisions,[4 10] elliptical incisions,[4] an incision along the side of the nose between the inner canthus and upper part of the nasal dorsum,[11] external incisions (no other description)[12 13] external incisions, plus opening of the cyst into the nasal cavity,[11] external incision plus bilateral osteotomy,[4 11] and intercartilaginous incision plus septal operation [14]

As far as I have been able to determine, there has been only one case reported in the American literature in which

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*Read at the Meeting of the Southern Section American Laryngological Rhinological and Otological Society Inc. January 25-26 1958 Memphis Tenn

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more space After removal of the cyst the nasal cavities were loosely packed to reposition the septal mucosa Pieces of autogenous nasal bone and bovine cartilage were used to help repair the defect The tissues were closed in layers and an adhesive dressing was put on the nose

On microscopic examination of a section of the cyst (see Fig 2) a cyst wall lined with stratified squamous epithelium was seen surrounding a slit like space containing desquamated squamous cells Hair follicles and sebaceous and sweat glands were present in the cyst wall At one level a foreign body inflammatory reaction had developed in an environment showing a number of sebaceous glands and hair follicles The microscopic diagnosis was dermoid cyst.

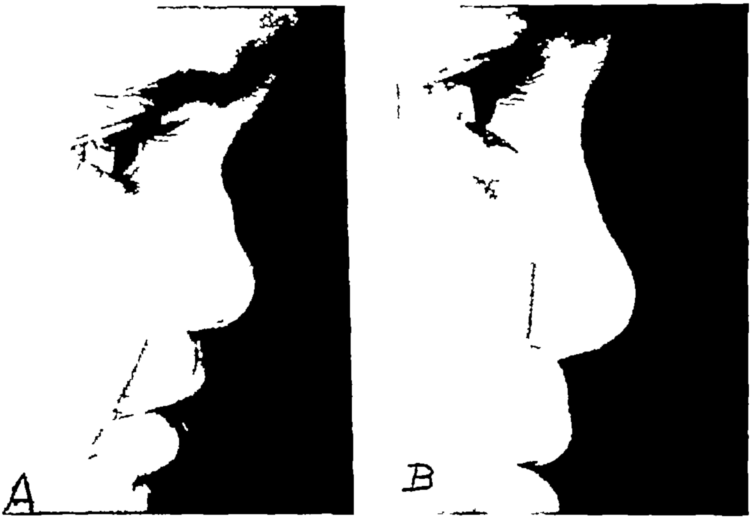

Fig 1 Case 1 A.—Note swelling over upper part of dorsum (1953) B—Five months after second operation (1957)

*Comment* After almost five years there is no evidence of recurrence of the cyst, however, the bovine cartilage became partly absorbed and was movable On June 16, 1957, intercartilaginous incisions were made, and the subcutaneous tissues were separated from the nasal framework The remainder of the bovine graft was removed, the bony parts were "freshened up," and multiple pieces of despeciated bone were inserted Fig 1-B, shows the patient five months after this operation

At this writing, seven months after the second operation, there seems to be no absorption of the inserted material In operation was not performed through an external incision over and along the side of the external nasal pyramid[14] Naturally, any case in which there is an opening, or sinus, along the midline will require an external incision to remove this area

Most of the reported cases have been from four large clinics,[4,10-12] and more than one-half on the patients were operated upon by surgeons of another specialty The midline incision seems to be the most favored by the oto-rhinolaryngologist Approximately 30 per cent of the patients had had previous surgical treatment (including incision and drainage)

All authors agree that the entire cyst must be removed In the most recent article of Crawford and associates[10] total surgical removal is considered much more satisfactory than curettage, chemicals or the electric cautery, as have been used by some in the past They also believed that an attempt should be made to repair any defect present, however, later repair may also be necessary

## REPORT OF CASES

*Case 1* A white girl aged two years, had had a lump on her nose for the preceding six months Occasionally some drainage was noted near the tip of the nose The child's maternal aunt has a small swelling between the inner canthus and the nasion

On examination a rounded, semifluctuant mass, measuring 4 x 4 mm was noted over the nasal dorsum (see Fig 1 A) It involved most of the bony vault and upper part of the cartilaginous vault At the tip of the nose in the midline was a small depression containing a hair that was perpendicular to the skin Slight pressure over the mass caused cheesy material to escape from the opening in the tip From palpation the impression was gained that the nasal bones were separated up to the frontal spine, and that much less bone was present than is normal for a child of two years On pediatric examination no other abnormalities or surgical contraindications were detected

On June 6 1953 after induction of endotracheal anesthesia a midline incision was made This was used because of the possible extension of the tumor and the smallness of the nose The mass above was exposed it lay between the nasal bones and upper third of the upper lateral cartilages and extended about 3 mm into the septum Below the cyst a stalk was followed to the tip where its opening to the outside was excised Another tract extended from the main body of the cyst upward and backward beneath the frontal spine to the region of the cribriform plate To be able to follow and visualize this tract some of the medial border of each remaining nasal bone had to be removed (this was saved to use in repair later) The nasal cavities were not entered at any time although the septal mucosa was reflected about 3 mm on each side to provide

Waters and lateral roentgenograms of the skull and facial bones were made A fairly well defined radiolucent shadow in the nasal bone was seen only in the lateral views.

On April 25 1955 after induction of endotracheal anesthesia incisions were made along the caudal margins of each lobular cartilage extending medialward into the anterior portion of the columella. After both lateral and medial crura were uncovered the soft tissues over the dorsum and along the side of the nose were undermined up to the nasion. The space in which to work was limited because of the small nose. It was therefore considered necessary to make an incision through the columella at its anterior extremity After mobilization of this area excellent exposure was provided to the whole dorsum of the nasal framework The cyst was separating the upper part of the upper lateral cartilages extending upward beneath the nasal bones and had caused some separation of their caudal ends It also extended along the dorsum of the bony and cartilaginous septum and this caused the thickening noted on intranasal examination. As dissection was carried out around the cyst, it was necessary to remove part of the mesiocaudal margin of each nasal bone to afford working space. The upper extremity extended to the posterior cephalic region of the nasal bones A small elliptical incision was made around the opening in the tip to remove the external opening of the caudal tract. This was closed with nylon sutures The bony defect was filled with the removed bone and some isogenous cartilage The incision in the columella was sutured with nylon A small amount of packing was placed in both nasal cavities and vestibules and an adhesive dressing was applied over the whole nose

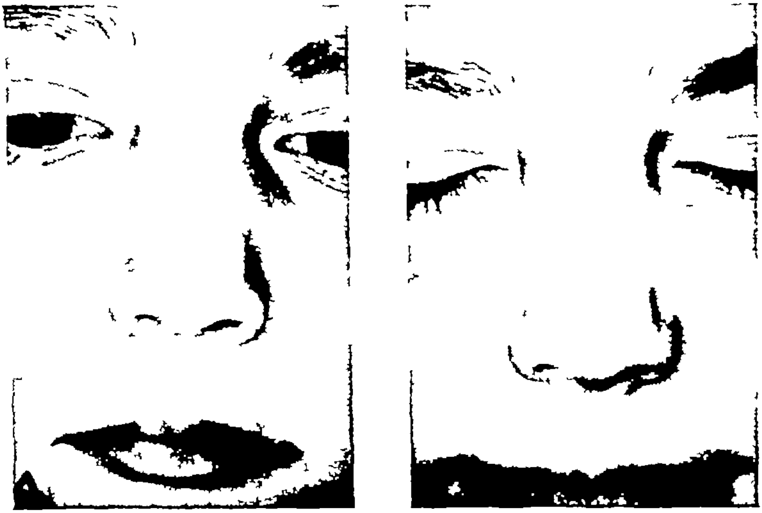

Fig 3 Case 2 A.—Preoperative view showing small pit opening at tip B—Photograph two-and-one-half years postoperatively

On microscopic examination of sections of the removed cyst fibrofatty tissue was seen containing an irregular cystic space lined with stratified such a case some substance has to be used to correct the defect Autogenous cancellous bone in the past has given the best results, but in such a young child, of course, it cannot be obtained If the grafts that were inserted become absorbed, some kind of graft will have to be employed, not only to relieve the deformity but also to help keep the soft tissues stretched so that eventually, if necessary, autogenous cancellous bone can be used

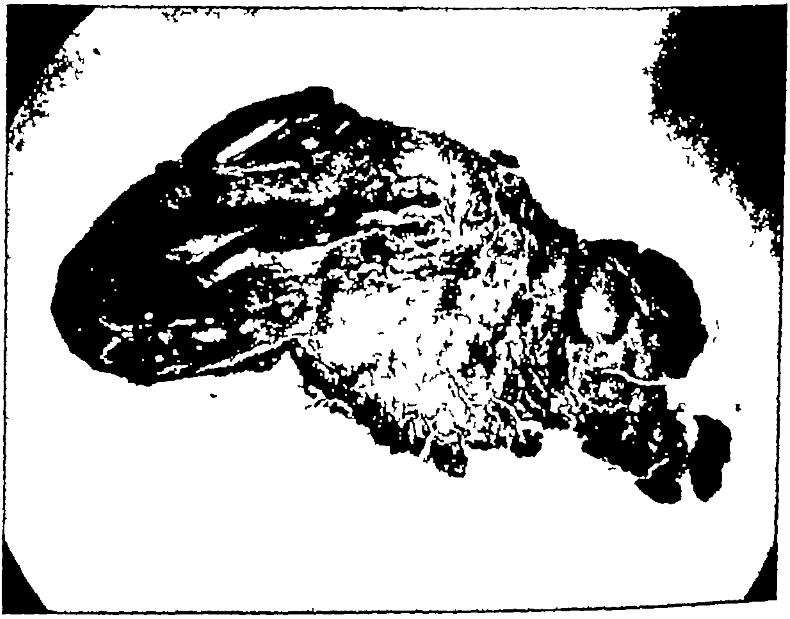

Fig 2 Case 1 Photomicrograph of dermoid cyst showing a cyst wall lined with stratified squamous epithelium surrounding a slit like space containing desquamated squamous cells Hair follicles and sebaceous and sweat glands are present in the cyst wall (× 20 H & E)

*Case 2* A white girl five and a half years old had had drainage from *the tip of the nose since birth During the preceding* year this area had bled on several occasions after injury The child had always been nervous and restless while sleeping

On examination at the tip of the nose in the midline was noted a small depression that contained hair perpendicular to the skin (see Fig 3A) With gentle pressure over the cartilaginous dorsum a thick cheesy material exuded On palpation the impression was gained that the cartilaginous dorsum was soft in the midline and that the caudal ends of the nasal bones were separated medially more than is normal Intranasal examination showed what was thought to be some thickness of the septum along both sides opposite the upper lateral cartilages bridge of his nose since birth and at least one hair was always present At times it became infected and drained what was thought to be pus

On examination a somewhat punched out area measuring 3 x 3 mm was seen on the nasal dorsum at the level of the caudal end of the nasal bones in the midline A few hairs were protruding (see Fig 5-A) no discharge could be expressed There was no external evidence of pathologic alterations below or above this area Intranasally the septum was deviated in its bony portion bilaterally

In lateral roentgenograms of the nose there was evidence of a radiolucent area about 0 5 cm wide extending from the anterior tip of the nasal bones posteriorly for about 2 cm where it was obscured by the overlying bones of the skull In the postero-anterior view were noted deviation and definite widening of the nasal septum in its antero-superior portion where again there was a faint radiolucent area There was no evidence of destruction of bone The changes were suggestive of a lesion in the antero-superior portion of the nose, causing some erosion of the nasal bones and occupying and causing some widening of the septum anteriorly Iodized oil (Iodochoral®) was injected into the sinus tract' and another roentgenogram was made (see Fig 6) The tract extended from the opening in the anterior portion of the nose posteriorly for about 4 cm where it was blocked apparently by a soft tissue mass

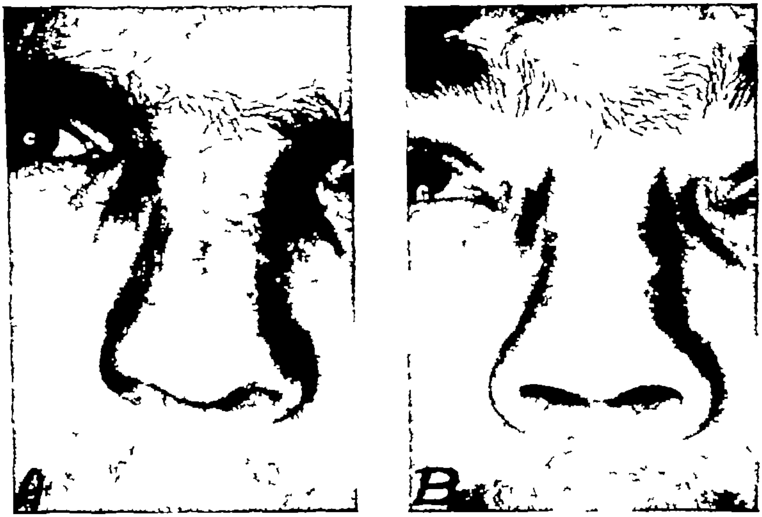

Fig 5 Case 3 A—Preoperative photograph shows hairs in the depression B—Photograph twenty-three months postoperatively

On Feb 22 1956 with use of a local anesthetic the septum was opened through a left hemi transfixion incision and the left septal mucosa was elevated back to the bony deviation The cartilaginous septum was separated from the bony septum and the mucosa over the right and left bony septum was elevated A bulging of the bony septum previously described as a deviation was opened and found to contain a cystic mass This squamous epithelium around which were rudimentary sebaceous glands and hair follicles containing hair shafts Several shafts were within the lumen of the cyst Adjacent to the cyst in one section was a foreign body reaction about hair shafts, due apparently to rupture of the cyst at one point not disclosed in these sections The microscopic diagnosis was dermoid cyst (see Fig 4)

*Comment* In this case the described approach was adequate, and no deformity has resulted after three years One week after the initial dressing the child's family reported that she was not so nervous as before operation, that she was breathing well through her nose for the first time in her life, and that she was able to sleep without making noises, having nightmares and pulling off the cover During the ensuing three years this result has persisted The parents also admit that they, too, have been somewhat rehabilitated, owing to what they call having a normal child

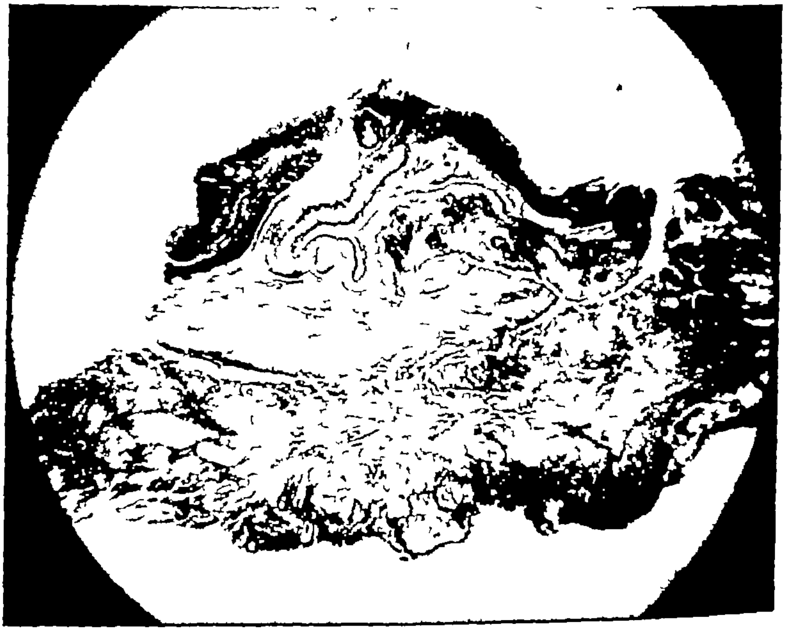

Fig 4 Photomicrograph of dermoid cyst in Case 2 showing fibrofatty tissue containing an irregular cystic space lined with stratified squamous epithelium around which are rudimentary sebaceous glands and hair follicles containing hair shafts (× 20 H & E)

*Case 3* A white man 29 years of age had had a 'deformity on the narrowed as it was uncovered posteriorly and extended almost to the face of the sphenoid (see Fig 7) The cyst uncovered in the bony septum was opened and contained a cheesy material An elliptical incision was made around the external opening and the soft tissues were undermined The stalk was dissected down between nasal bones and upper lateral cartilages and then followed into the exposed area in the septal space All attachments were severed and it was removed To correct the deformity between the nasal bones and also to help narrow an abnormally wide bony vault bilateral osteotomy and infracture were performed Bone was replaced between the septal flaps and the incision in the septum was closed The external incision was closed in layers after some autogenous bone and septal cartilage had been placed over the dorsum Adhesive and stent dressing was applied

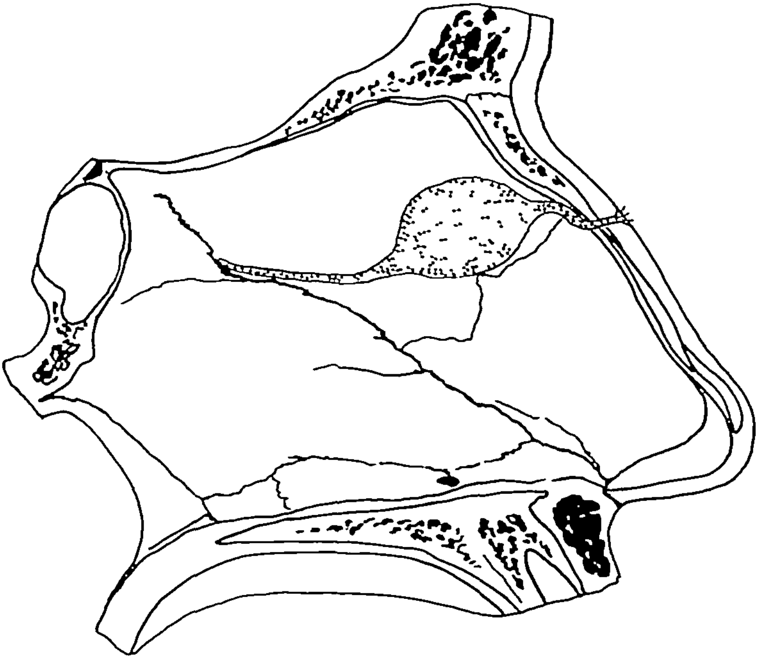

Fig 7 Diagram of extension of cyst in Case 3

On microscopic examination of sections of the removed specimen a channel or cavity lined with stratified squamous epithelium containing epithelial debris and blood was seen (see Fig 8) In the wall surrounding the cyst numerous hair follicles and sebaceous and sweat glands were present. The microscopic diagnosis was dermoid cyst

*Comment* All of the cyst was removed through the septal exposure except, of course, the external portion Two other cases of cysts of the septum[11 14] have been reported, but they

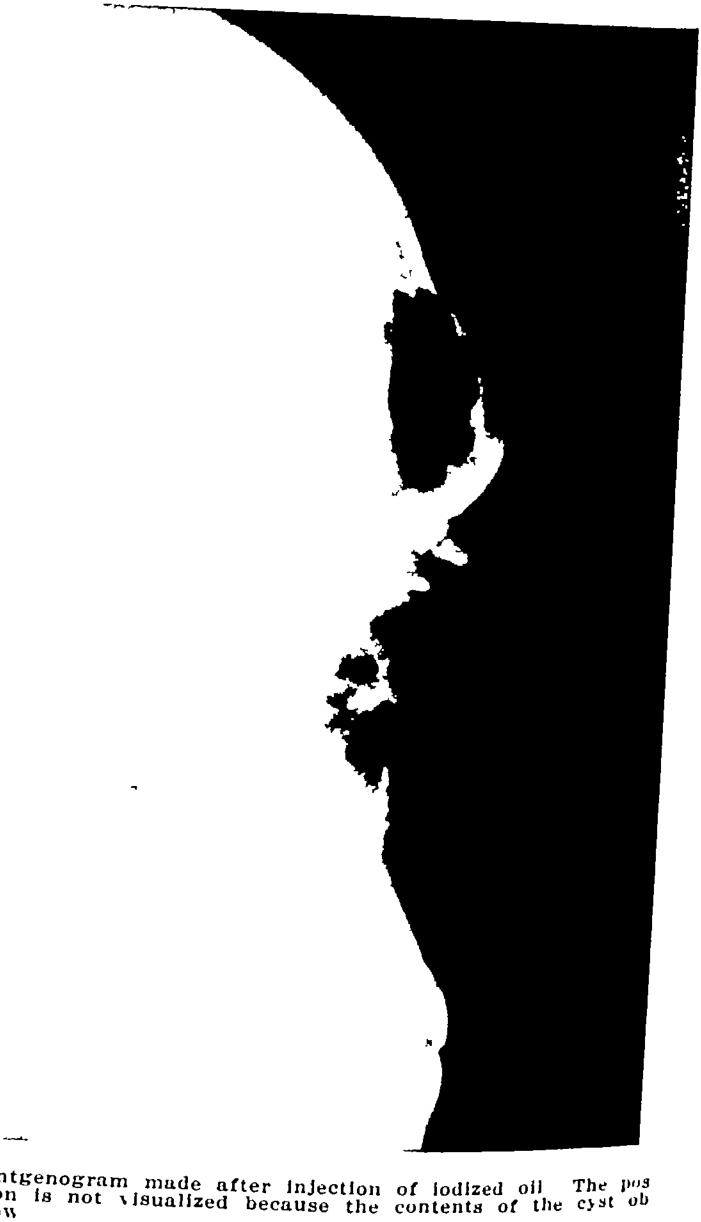

Fig 6 Roentgenogram made after injection of iodized oil The posterior extension is not visualized because the contents of the cyst obstructed its flow

pathologic alterations found Intercartilaginous incisions will provide good exposure up to and including the frontal spine One may also remove a mid-dorsal cyst and inspect the area posterior to the nasal bones and frontal spine if the cyst extends into this area It is also possible to go down into the nasal septum through the upper lateral cartilages and combine this procedure with a septum operation for complete removal of a cyst This was part of the procedure described by Juers,[14] and was used in Case 3 herein reported

If the stalk comes down to the tip, another approach is possibly better Incisions may be made along the caudal margins of both lobular cartilages (the slot incision described by Cottle[15]) extending down along the columella The tissues external to the cartilage are uncovered, and the surgeon, continuing upward, may uncover the whole pyramid By adequate and careful dissection the pathologic alterations can be visualized and removed providing the nose is not too small In an extremely small nose, to obtain more working space, the columella can be severed at its anterior extremity, as was done in Case 2, this leaves only a minimal scar

*Another helpful procedure is osteotomy* Its use has been reported previously in two cases[4] This helps, in that the bony dorsum may be narrowed, it also helps to correct a deformity after part of the bone has been removed and helps insure formation of a good roof over the bony vault[16] This procedure was used in Case 3

A secondary operation to correct a deformity created by the cyst and its removal is essential in some cases[10] Here again rhinoplastic procedures are invaluable, since most of these probably require attention to the bony dorsum This area is easily reached through the intercartilaginous incisions Such a procedure was used in a secondary operation in Case 1, in which the remainder of an old graft was removed, and some other grafts were reinserted It is also possible to work in this area through the slot incisions should additional procedures need to be performed on the cartilages of the lobule were both located in the septal cartilage, also in the cases reviewed only two osteotomies[4, 11] had been performed and they were not associated with the septal cases

At this writing, practically two years postoperatively, there is no evidence of recurrence of the cyst A serious psychologic problem has become greatly improved

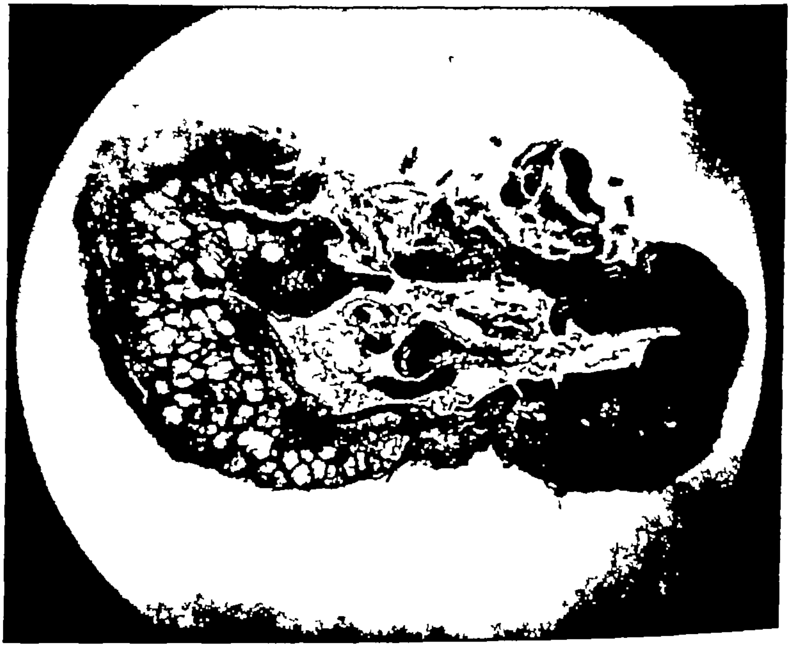

Fig 8 Photomicrograph of dermoid cyst in Case 3 showing a cavity lined with stratified squamous epithelium containing epithelial debris and blood In the wall surrounding the cyst numerous hair follicles and sebaceous and sweat glands are present (X-20 H & E)

## DISCUSSION

No routine operative procedure can be employed in these cases because the pathologic process varies Even though the incision over the nasal dorsum does not cause a bad deformity, there is a scar In patients who have only the small "pit opening" at the tip, and those who have a mass along the junction of the upper lateral cartilages and the nasal bones, the possibility of using a rhinoplastic procedure is real Naturally the procedure used depends upon the diagnosis and

# PERNASAL TRANSSPHENOIDAL YTTRIUM IMPLANT OF THE HYPOPHYSIS *†‡

W M S IRONSIDE, M D ,
(By Invitation),
and
ROBERT D MOSELEY, JR., M D ,
(By Invitation),
Chicago, Ill

In 1953, Luft and Olivecrona demonstrated the beneficial results that could be obtained with hypophysectomy in certain cases of advanced cancer After much experience it now appears that only the hormone dependent cancers of the breast and prostate are likely to benefit

As a result of the interest in hypophysectomy, numerous routes to the gland have been used, and methods of excision or destruction employed The aim, of course, is to devise a simple operation which will cause minimal distress to the patient, as many of these coming to this type of surgery are severely debilitated, at the same time it is necessary to insure effective destruction or removal of the gland

It is as well to recall some of the routes which have been used in the past to reach the hypophysis Although the transcranial route was one of the first to be used, the mortality rate was so high that by the end of the first decade of this Century interest was being developed in the nasal routes, but even with the transseptal,[2] lateral rhinotomy,[3] sublabial routes[4 5 6] and their numerous modifications,[7 8 9] the mortality rate in some series ran as high as 30 per cent By the 1930's the great advance in neurosurgical techniques, and the need

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*Read at the meeting of the Middle Section American Laryngological Rhinological and Otological Society Chicago Ill Jan 14 1958

†From the Departments of Otolaryngology and Radiology The University of Chicago

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## SUMMARY

Three cases of midline dermoid cysts of the nasal dorsum have been presented Attention is called to the feasibility of using rhinoplastic procedures in applicable cases with the idea of leaving less visible postoperative defects

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a source of Gamma rays, in the form of two tubes by the pernasal transphenoidal route with the assistance of a complicated head holder and needle director The procedure is controlled by intermittent radiography Radon was used because Pattison and Swan[14] in 1933 successfully treated a case of basophil adenoma of the pituitary by introducing two radon tubes into the sella tursica through the transcranial route Forrest found that the Gamma irradiation required to destroy the pituitary also affected surrounding structures such as the optic nerves, therefore, yttrium 90 with its high activity over a short radius is now being used

From the experimental work of Marinelli[15] it was considered that complete destruction was more likely to follow the implant of multiple discrete sources, 1 mm by 2 mm of yttrium, rather than the two larger sources, 2 mm by 6 mm, as used by Forrest, however, it was obvious that the nasal route held many advantages, the most important of which was the lower mortality rate, and adequate local anesthesia was considered sufficient to perform the nasal operation, a considerable advantage when dealing with these rather debilitated patients

It was felt that only under direct vision could the needle be directed through the nose to the anterior wall of the sphenoid sinus without injuring the nasal mucosa, and that only with the assistance of image intensifiers (Muller Surgex units with Phillips intensifier tubes) could multiple yttrium beads be deposited with any degree of accuracy throughout the pituitary gland The image intensifiers permit continuous fluoroscopic guidance throughout the procedure without exceeding the permissible exposure dose to the surgeon

The method evolved is as follows Under premedication of Nembutal 180 mgm, given two hours, and Demerol 100 mgm, given one hour before operation, the patient is brought to the operating room and very carefully positioned on the table with the occiput low in a modified Rose's position (see Fig 1) The reason for this position is to allow the axial image intensifier to be brought into place This positioning must be done with great care and gentleness in those patients with to remove totally, rather than partially, tumors involving this gland, the transcranial approach became once more the route of choice With the advent of the sulphanamides and antibiotics the mortality rate of this procedure steadily declined That this route was used by Luft and Olivecrona for excision of the gland in their pioneer work is not surprising

The report of Forrest and Peebles Brown[5] in 1955 renewed interest in the nasal route, and numerous modifications have been devised, but these routes are used mainly for the introduction of radioactive compounds rather than for surgical excision of the gland

Regarding destruction of the gland, probably the greatest experience has been with surgical excision, however, an increasing number of cases are being subjected to procedures in which the gland is necrotized by implanting radioisotopes External radiation methods, such as proton beam therapy, are at present in an experimental stage, and experience with them is very limited

The method devised is based mainly on the work of two groups one at the University of Chicago, the other at the University of Glasgow

Rasmussen, Harper and Kennedy,[11] of the University of Chicago, in 1953 suggested that yttrium 90, a pure Beta emitter, if implanted in the form of multiple discrete beads, described by Kisieleski[12] in 1950, could effectively destroy the hypophysis The transcranial route was used for placement of the beads, and in practice it has become obvious that even though the gland is under direct vision at the time of operation, accurate deposition of the beads is exceedingly difficult Unfortunately, due to the very nature of the operation, it is difficult to obtain a field free of metal impedimenta and to position the patient's head, so that the use of continuous radiologic control is practical, furthermore, the operation is attended by the usual mortality rate, associated with such a neurosurgical procedure under general anesthetic

Forrest[13] and his associates, of the University of Glasgow, reported in 1956 their results obtained by implanting radon, to the anterior wall of the sphenoid sinus Here the position of the tip and direction of the needle is checked by the intensifiers in both the axial and lateral views before the tip of the needle is advanced into the sphenoid sinus Into the sinus in instilled 1 5 cc of a penicillin topical thrombin solution, each cc of which contains 10,000 U of penicillin and 200 U of thrombin Under continuous guidance the needle

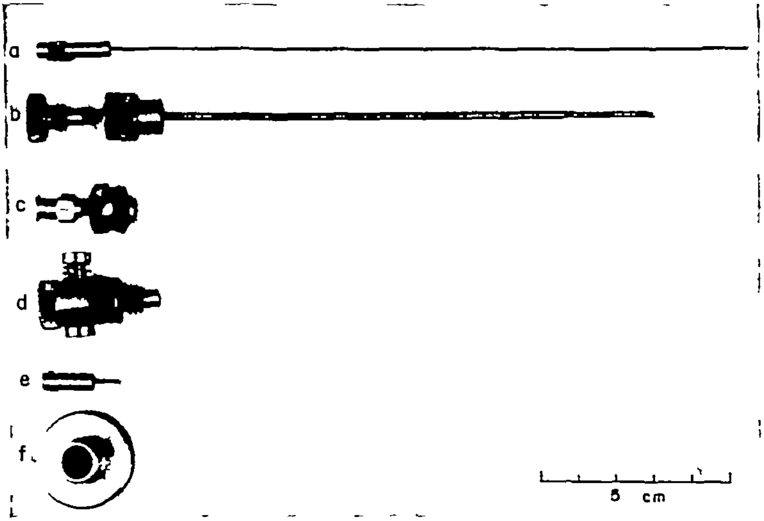

Fig 2 Special instruments for introducing yttrium beads a Stillette which passes through cartridge (c) and cannula (b) b trocar and cannula (17 gauge) c adapter for connecting syringe to cannula (b) during installation of penicillin thrombin solution d cartridge when mounted on stand (f) bead dropped into left end and pushed home with cartridge pin (e) while spring on transverse cylinder is compressed on releasing spring bead is trapped in cylinder quartz window permits observation of bead on its way through cartridge when stillette (a) is introduced e cartridge pin f stand for cartridge during loading

is advanced into the medial portion of the left half of the pituitary A posterior bead is deposited before withdrawing the tip a few mm and depositing an anterior bead The tip of the needle is then withdrawn into the sphenoid sinus and the needle angled laterally before being advanced once more into the gland Again a posterior and an anterior bead are deposited, and this time in the lateral portion of the left half of the gland Similar maneuvers are carried out on the right side (see Fig 3) spinal metastases, as any extreme degree of cervical extension will cause pain

Local anesthesia is then induced with cocaine, 5 per cent, by instilling 0 5 cc into each nostril with the head in three positions first with the head turned to the left, then to the right and finally in the midline Occasionally when the optimum position of the head and neck cannot be obtained the anesthesia is supplemented with a Sluder block (see Fig 1)

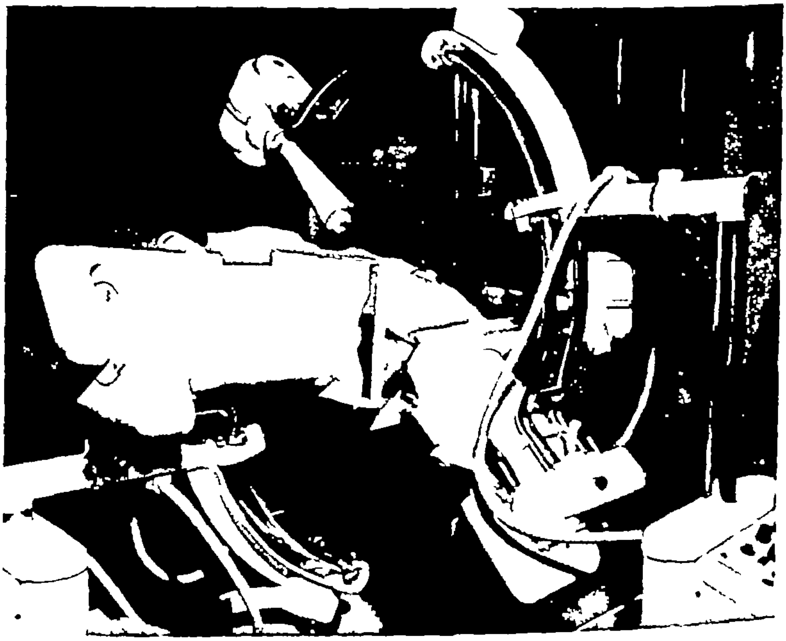

Fig 1 The patient in position on the table with the neck and head extended Image intensifiers are draped during operations

At this stage the face is prepared and drapes applied The two intensifiers are also draped and brought into position The yttrium beads, 1 mm by 2 mm, with an activity of approximately 1 mc, are then loaded into the cartridges under water One cm of water gives adequate shielding from the irradiation of these beads

The strengthened 17 gauge needle (see Fig 2) is then passed into the left nostril and guided under direct vision ment has not been started until signs of hypothyroidism develop, and this does not occur for at least two months postoperatively

## MATERIAL

Although some 40 of these operations have now been carried out since June, 1957, only the first 26 will be reviewed, for at least two months are required to determine the effects of the procedure It is as well to point out at this stage that these cases were unselected, insofar as no consideration was given to the age and general condition of the patient, the type of the primary tumor or site of metastases and previous treatment received by the patient They were all considered to be unlikely to benefit from further surgery, radiotherapy or endocrine therapy, furthermore, the early operations were performed on patients who were in a very advanced, or even terminal stage of metastatic disease

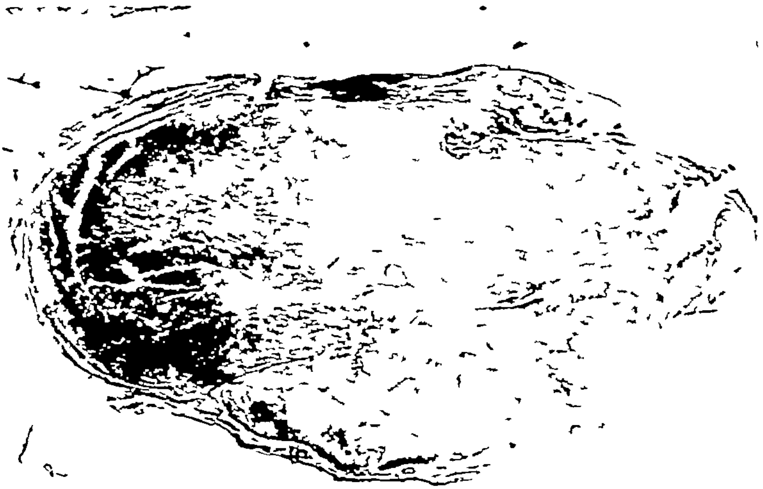

Fig 4 H and E. × 9 Pituitary obtained 15 days postoperatively from Case 1 showing almost total destruction

Generally eight beads are implanted, but as many as 11 and as few as six have been used Variations in the size of the sella and the accuracy of deposition of individual beads determines the total number deposited Variations in the position of the nasal and sphenoidal septum can be an inconvenience, but do not prevent an adequate implant Serial sectioning of the few pituitaries obtained at autopsy have revealed that an average of better than 90 per cent destruction has been obtained by this method (see Figs 4, 5)

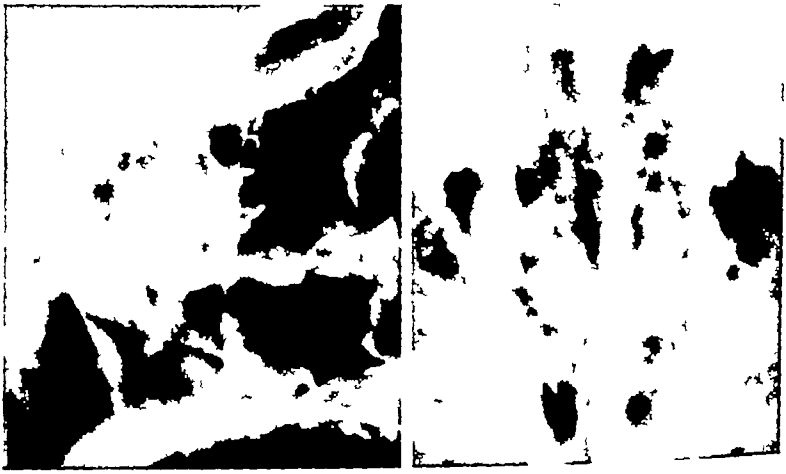

Fig 3 Implant obtained in Case 1 Lateral and axial views

Even severely debilitated patients stand the outlined procedure very well On two occasions, however, it has been necessary to give an additional 50 mgm of Demerol intravenously while the patient was on the table Only one patient was deemed unfit for operation, when she became drowsy and confused on the day tentatively planned for operation, she died nine days later

## MAINTENANCE

All patients subjected to this procedure have required a maintenance dose of Cortisone, on the average this has been 50 mgm daily Pitressin tannate has been administered to those patients developing diabetes insipidus Thyroid replace-with a IVth nerve paralysis This is embarrassing for the patient, due to the drooping of the lid, but is no real handicap Two developed a temporary VIth nerve paralysis, which was rather distressing, due to the double vision which resulted One case of IIIrd nerve paralysis has started to clear after being present for two months

Examination of pituitaries obtained at autopsy have confirmed the suspicion that these paralyses arise from placing beads too far laterally The technique has been modified accordingly Surgical trauma at the time of operation plays no part in this complication, as the onset of paralysis is from the third to the sixtieth day

TABLE I

Complications in 26 Operations

| | |
|---|---|
| Extra-ocular N palsies | 10 |
| Cerebrospinal rhinorrhea | 4 |
| Meningitis | 2 |
| Anesthesia of face | 1 |

Using this route it was expected that cerebrospinal rhinorrhea might present—it has occurred in four patients In two patients it lasted for a number of months One was the patient already mentioned, who was suspected of having died from meningitis two months postoperatively The other was a man who had metastatic carcinoma of the prostate The rhinorrhea lasted two-and-a-half months, but the patient has now returned to work The two other cases of rhinorrhea were of a very temporary nature

Starting with the twentieth case topical thrombin has been injected into both sphenoid sinuses, with penicillin, at the time of operation, as indicated It is interesting that all these cases of rhinorrhea occurred within the first 14 operations, but this complication still occurs In the last 26 cases, two have developed temporary rhinorrhea

Meningitis was encountered twice first, in the patient who is suspected of having died from this complication, and the other, in a patient who against advice blew her nose

## MORTALITY

Of the 26 cases under review there were no deaths directly due to the procedure One patient died two months postoperatively, and from the doctor's account of the terminal stage death probably resulted from meningitis Unfortunately, autopsy was not obtained This patient had developed a permanent cerebrospinal rhinorrhea two weeks postoperatively, and although she returned to the hospital it was decided that she was unfit to undergo transcranial closure of the defect, and was sent home again This indicates rather well the "poor risk" cases that stand the procedure so satisfactorily

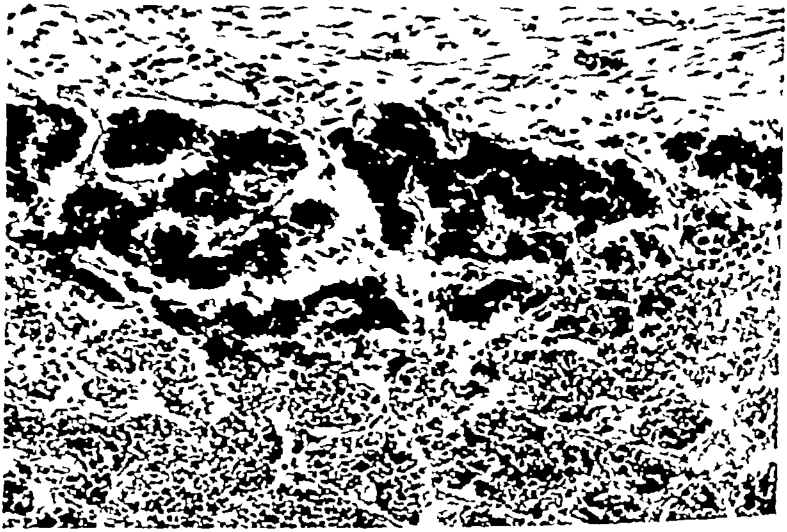

Fig 5 H and E X 150 of surviving cells note sharp line between surviving and necrotized cells

## COMPLICATIONS

Thirteen out of 26 patients developed one or more of these complications

By far the most frequent complication, ocular nerve paralysis, developed in no less than 10 patients Eight suffered from a IIIrd nerve paralysis, either alone or in combination impairment, frontal lobe or hypothalamic damage, or brain abscess formation such as have been reported in other series

## RESULTS

Of these 26 patients 21 had a primary lesion of the breast, four of the prostate and one of the ovary

TABLE II

Operations Performed

| | |
|---|---|
| Performed for Metastatic Carcinoma of Breast (F—20 M—1) | 21 |
| Performed for Metastatic Carcinoma of Prostate | 4 |
| Performed for Metastatic Carcinoma of Ovary | 1 |
| Total | 26 |

## CANCER OF THE BREAST

The 21 cases of metastatic cancer of the breast consisted of 20 females and one male

TABLE III

Carcinoma of the Breast

| | |
|---|---|
| Surviving— | |
| Unchanged | 5 |
| Improved | 10 |
| Dead— | |
| Unchanged | 5 |
| Improved | 1 |
| Total | 21 |

Eleven appared to benefit from the operation

The estimation of the result of the operation is based on clinical observations such as cessation of vomiting, increase in appetite, weight gain, changes in size of cutaneous or subcutaneous lesions and X-ray studies of metastatic lesions Symptomatically, relief of pain has been the most dramatic feature of those gaining benefit from the procedure, however, only four have shown a true regression with sclerosis of esteolytic deposits, etc (see Figs 6, 7, 8) vigorously She suffered a temporary leak of cerebrospinal fluid and developed meningitis This responded to antibiotic therapy and the rhinorrhea ceased

During two procedures pellets were misplaced In one it is assumed that they entered the cranial portion of the left carotid and were whipped into its branches, two settling in the distribution of the middle cerebral of the same side, and another entered the circle of Willis, crossed to the other side and came to rest in the distribution of the anterior cerebral artery There were no after effects

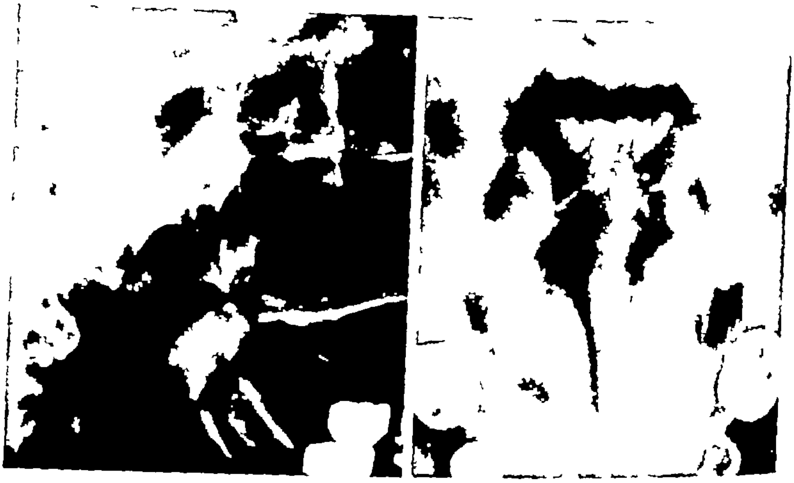

Fig 6 Lateral and axial views of implant obtained in Case 9

In the other case a pellet came to lie at the right petrous apex As a consequence of this the patient has developed a mild sensory loss on the right side of the face in the distribution of the ophthalmic and maxillary divisions of the Vth nerve

Although the complication rate in this series has been fairly high it can be reduced with experience This is evidenced by the absence of any complications following operation in the last ten patients subjected to this procedure since December 1, 1957

There have been no instances of anosmia, visual field

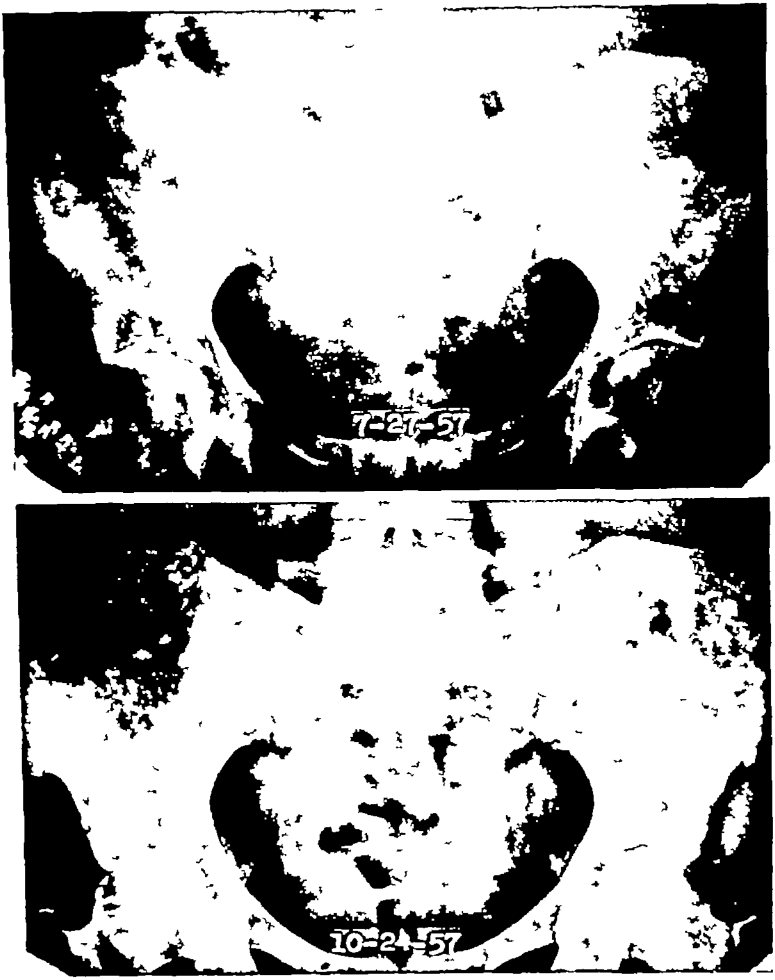

Fig 8 X-rays of pelvis before and 10 weeks after operation in Case 9

## CARCINOMA OF THE PROSTATE

All four patients showed improvement after yttrium implant This was evidenced by return of appetite, disappearance of bone pain, resumption of ambulation or return of normal urinary function

The patient who had metastatic carcinoma of the ovary did not gain any benefit from the operation

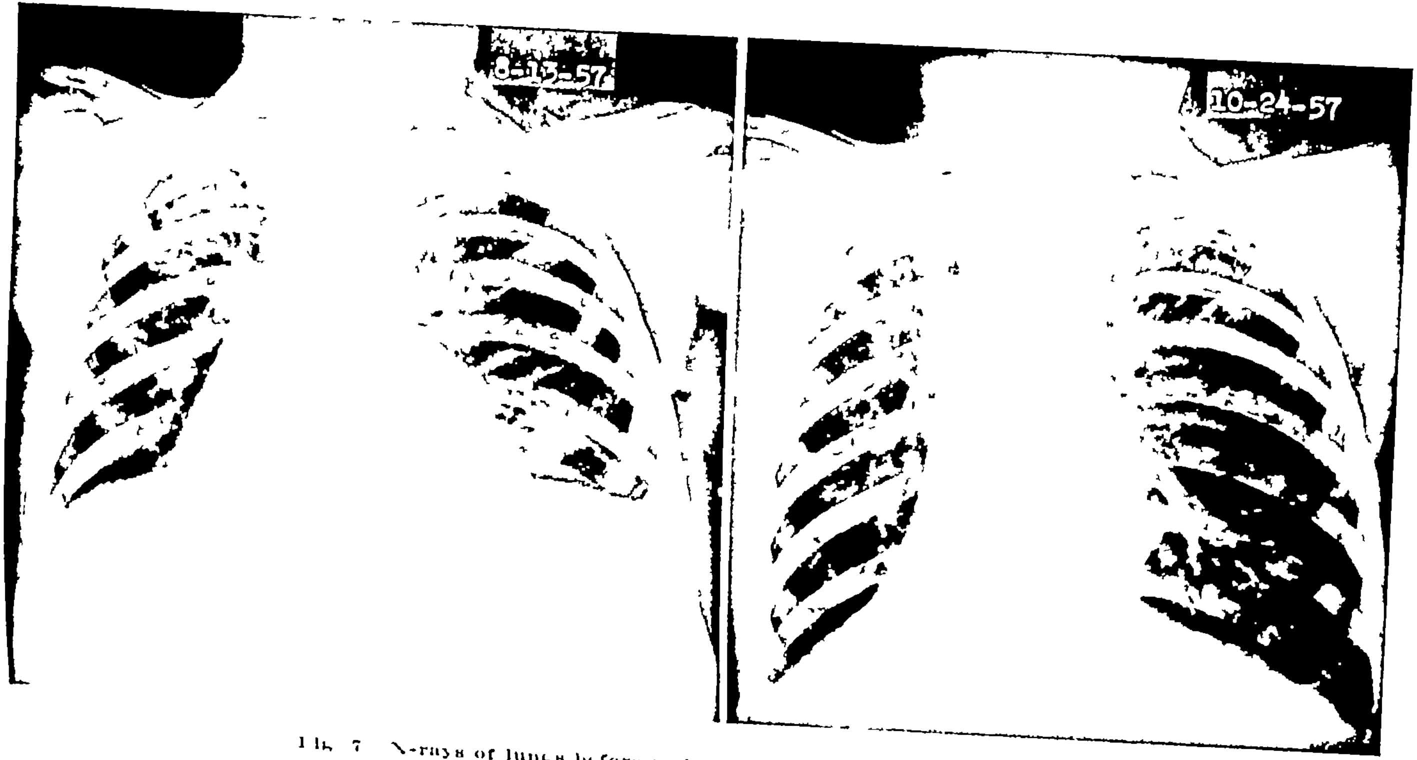

Fig. 7 X-rays of lungs before and 10 weeks after operat

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## REHABILITATION OF THE LARYNGECTOMIZED

The University of Texas Postgraduate School of Medicine and the Houston Speech and Hearing Center will present the second training course in "The Rehabilitation of the Laryngectomized" from June 9 through 20, 1958

The course this year will be altered in several ways as a result of experience gained from last year's presentation and will cover Vocational Adjustment, Anatomy of the Speech Mechanism, Normal Speech and Voice Production, Esophageal Speech and Voice, Laryngeal Surgery, Radiation Therapy, Facts about Cancer and Techniques in Teaching Esophageal Speech

The general presentation will combine both the clinical and didactic approach

Applications for Traineeships, which are limited in number, should be made as soon as possible, and will not be considered after May 19, 1958

Inquiries concerning this course should be directed to The University of Texas, Postgraduate School of Medicine, 410 Jesse Jones Library Building, Texas Medical Center, Houston 25, Texas

## CONCLUSION

As has been stated, virtually all patients referred with advanced cancer of the breast and prostate have been accepted for this procedure It is felt that with better selection of cases the percentage of patients benefiting will increase, and with more experience and knowledge gained from autopsy studies the complication rate will continue to decrease

## SUMMARY

Routes to the pituitary and methods of destruction are reviewed

A simple method of yttrium implant of the hypophysis with continuous fluoroscopic control and under local anesthesia is outlined

The results, obtained by 26 such procedures performed on patients suffering from advanced cancer are presented*

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*We acknowledge our indebtedness to Dr J P Evans for his assistance and advice and to Dr P V Harper Jr for arranging the supply of yttrium 90 fore, tried maneuvers in which a rocking force was applied through the incus and incudo-stapedial joint This resulted in a greater success rate, but crural fractures were still too frequent, and it soon became obvious that many fixed footplates could not be mobilized by forces exerted through the crura The procedure passed rapidly, therefore, into the next stage in the evolution of methods to mobilize the footplate, this being the direct method by which cutting, prying, hammering, needling, chiseling and drilling techniques are used directly on the margins of the footplate Among the first to use the direct method extensively in this country were House[2] and Goodhill,[3] who needled the margins of the footplate, whereas in Europe, Heermann[4] of Essen reported success with chisels, and Meurman[5] of Helsinki with serrated knives More recently, Portmann[6] of France and Shea[7] in this country have utilized a micro-drill to lyse otosclerotic foci, but their experiences are, as yet, not adequate to predict whether the method will enhance existing techniques

I (H F S ) visited Professor Zollner at the University of Freiburg in November, 1956, and saw him demonstrate the method of mobilizing the stapes with the chisels of Heermann I used these instruments on a series of patients, and when Heermann attended the International Congress of Otolaryngology in Washington, D C , in May, 1957, I had an opportunity of discussing the method further with him Since that time, I have been using the chisels exclusively in all our mobilization operations The early results are good enough to justify enthusiasm for the method, and the main purpose of this paper is to describe the technique and to present our experiences with it We will also show our results with previous techniques

## GENERAL INFORMATION

Our indications for surgery have been the same from the beginning, i e , any patient with a clinical picture of otosclerosis who has a bilateral air conduction hearing loss averaging over 30 db for the speech frequencies (500, 1000, 2000), with no restrictions as to age or level of bone conduction thresholds Patients who have no chance of improving

# RESULTS WITH THE CHISELS IN STAPES MOBILIZATION*

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When the stapes mobilization operation was first described by Rosen in 1954[1] there were many skeptics. Some said that the operation was doomed to failure because labyrinthitis was apt to ensue in many patients, some felt certain that early re-ankylosis would occur, and others said that the operation had been tried before and discarded because of poor results. Time has shown that this early skepticism was not justified, for the greater proportion of successfully mobilized patients have not experienced re-ankylosis, and very few have had serious complications. We must attribute much of the success of the stapes mobilization operation to the invention of the operating microscope with built-in light, which finally has provided adequate visualization for the otologists, and to the development of antibiotics which are used to reduce the incidence of post-operative infection.

The technique of mobilization has undergone a rapid transition from the original Rosen method to direct footplate techniques which have resulted in a higher percentage of successful results. The original technique described by Rosen consisted of applying pressure to the neck of the stapes so as to mobilize the footplate by tilting it in the oval window. Many otologists, including Rosen, were dissatisfied with the results because of the high incidence of crural fractures and, there-

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speech audiometer, in a two-room testing unit, using monitored live voice techniques

Thresholds for bone and air conduction throughout have been stated in terms of the equivalent S R T as determined by the Fletcher formula The Fletcher formula is the average of the two best threshold responses for 500, 1000 and 2000 c p s

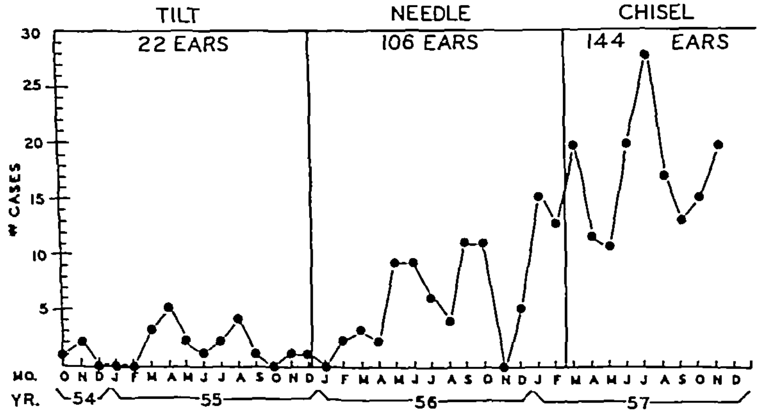

Fig 1 Chart showing the operative method number and date of 269 stapes mobilization operations

## CLASSIFICATION OF RESULTS

*1* Successful

*a* 30 db or better pure tone threshold

*b* 20 db or smaller bone-air gap

*2* Improved

10 db or more improvement of pure tone threshold but not successful

*3* Unchanged

Less than 10 db change of pure tone threshold

*4* Hearing Loss

10 db or more loss of pure tone threshold

their air conduction thresholds to practical hearing levels because of sensory-neural deafness and who experience a successful mobilization were usually greatly pleased with the comfort afforded by the lower amplification requirements The ear with the poorest hearing was always operated first, and only if the hearing improved beyond the opposite ear was the opposite ear operated Patients with unilateral otosclerosis were subjected to surgery only if they felt that their hearing loss was an occupational or social handicap (seven of 269 ears)

The operations all were performed with local anesthesia by the trans-tympanic route The head light and 2 5 power loupe were used for some early cases, but nearly all were done with the aid of a Zeiss operating microscope For the past year, this instrument has been used for the entire operation

The patients were discharged from the hospital the day following surgery unless they complained of vertigo Tetracycline, 250 mgms every six hours, was given for five days post-operatively

## CRITERIA OF SUCCESS AND FAILURE

We have not rated our patients into classes of predicted success, as is done for patients being considered for fenestration surgery, because for stapes mobilization we are not restricted by the bone conduction levels From October 25, 1954, to December 1, 1957, two hundred and sixty-nine mobilizations were performed, most of these being performed in the past year We have determined the success rate for each of the three groups of patients in which the tilt (22 ears), needle (106 ears) and chisel (144 ears) techniques were used (see Fig 1

We (A B G and M R C ) administered all pure tone tests in acoustically-treated rooms with an ambient noise level of less than 50 db in the critical frequency bands with commercially available clinical audiometers The calibration of each audiometer was standardized regularly with the Allison calibration unit, Model 3A Speech tests were administered either with the above equipment or, using the regularly calibrated

The results were far more gratifying than those accomplished with the tilt technique, but at the end of six months, 20 per cent of the early successes had again lost their gain

## CHISEL METHOD

Whereas the mild and moderate ankylosis could be mobilized quite satisfactorily with needles, the method was not often successful in mobilization of the more severely ankylosed footplate The next logical step was the use of chisels to cut through the otosclerotic foci For the development of the technique and the design of the instruments, we are indebted to Heermann I may not use the instruments in precisely the manner that he does, but this is not important as long as the end result is lysis of the stapedial footplate in continuity with one or both crura Heermann first designed a slightly curved and a straight chisel* which I now refer to as the "heavy" models and which I use first on all but the very thin otosclerotic foci About six months ago he designed lighter models which I use continuously, and refer to as the curved, reversed-curved, and straight "light" models In order that the reader may gain a clear impression of the shape and size of the chisels in relation to the stapes, they are shown to scale in Fig 2

TABLE II

Needle Method—106 Ears

| | | | |
|---|---|---|---|
| Early Results (1 month) | | | |
| Successes | Threshold | 60 | |
| | Bone-Air Gap | 6 | 62% |
| Improved | | 11 | 10% |
| No Change | | 27 | 26% |
| Loss | | 2 | 2% |
| No Early Record | | 1 | 1% |
| Late Results (Average 6 months) | | | |
| Successes | Threshold | 44 | |
| | Bone-Air Gap | 6 | 47% |
| Improved | | 10 | 9% |
| No Change | | 33 | 31% |
| Loss | | 4 | 4% |
| No Late Record | | 9 | 9% |

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*Available from F L. Fischer Co Freiburg im Breisgau Germany

The three groups were rated in terms of early and late successes, the early successes being determined by audiometric tests taken about one month after operation, and the late successes three months or longer after operation, thus, the average time after operation for the late tests was eighteen months for the "tilt" ears, six months for the "needle" ears, and four months for the "chisel" ears

## TILT TECHNIQUE

After I first saw Rosen demonstrate his method in October, 1954, I attempted to follow it  As much as I dislike introducing new terminology, I cannot bring myself to describe my own attempts to mobilize by applying pressure to the neck

TABLE I

Tilt Method—22 Ears

| | | |
|---|---|---|
| Success | | |
| Early (1 month) | 4 | (18%) |
| Late (average 18 months) | 3 | (14%) |
| Improved | 6 | |
| No Change | 12 | |
| Loss | 1 | |

of the stapes as the "Rosen method", for to do so would be no compliment to Rosen  Obviously he had developed a degree of skill in applying this force which eluded me, for my attempts to rock or tilt the stapes very often resulted in crural fractures  The results are shown in Table I

## NEEDLE TECHNIQUE

I was very grateful when House and Goodhill showed me their techniques in January, 1956, which consisted of the skillful application of force to the head of the stapes by a needle and, if that failed, by prying, pushing and cutting the margins of the footplate with sharp needles, great care being directed at mobilizing the footplate without breaking the crura  During 1956 and early 1957 I utilized the needles to the best of my ability on one hundred and six ears  Results are shown in Table II sary, to acquire the best possible view of the crura and footplate I make no attempt to mobilize the stapes with transincudal or trans-capitulum force, but proceed immediately to make the first chisel placement anterior and adjacent to the anterior crus so as to cut through the anterior otosclerotic focus

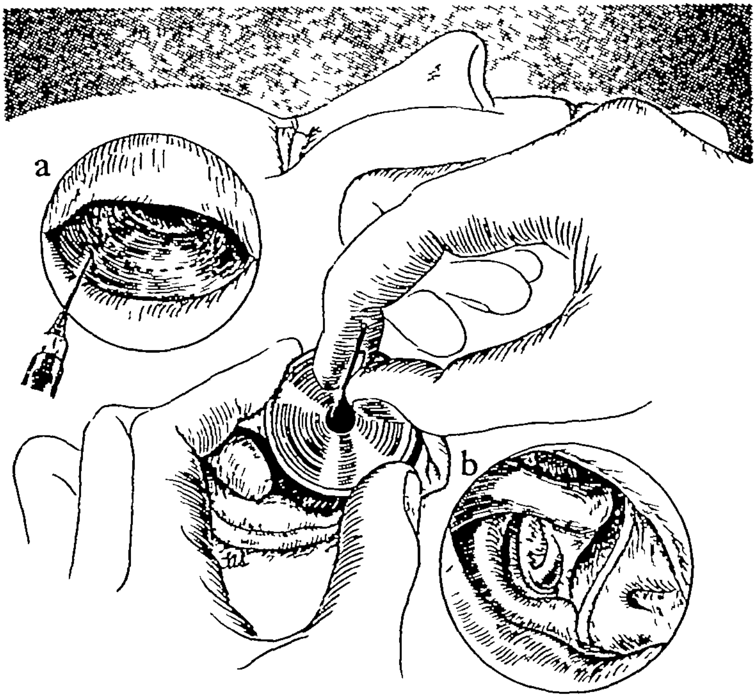

Fig 3 a. Sites of injection for anesthetic agent (3 dots) and location of meatal incisions (broken line) b Typical view of operative field Center Method of placing chisel utilizing 10 to 16 power magnification

A handle can be purchased to hold the chisels, but I prefer to hold the chisel in position by grasping the small tab located on the shaft with the bare fingers of either the left or the right hand, whichever is the most convenient, while the oppositie hand holds the speculum The nurse or assistant taps the chisel with a small hammer, using light to heavier blows, as directed by the operator Sometimes the nurse holds the speculum, leaving the operator's opposite hand to

The injection sites, skin incisions, position of the hands when holding the chisel and the normal view of the operative field are seen in Fig 3 The skin flap must be large enough to cover the defect left by removing bony annulus posteriorly and to allow inspection of the round window Bony annulus can be removed with either curettes or burs Accumulation of bone dust makes the bur somewhat objectionable Sometimes electrocautery is needed to control bleeding from the skin incisions The chorda-tympani nerve usually is reflected downward, but occasionally upward, so as to preserve it The stapes is touched gently with a needle to determine whether it is fixed In only one ear (of 269) was a mobile stapes found, and this ear was one of three with total round window closure, the others having stapes ankylosis in addition Curtains and bridges of mucous membrane are cut away, if neces-

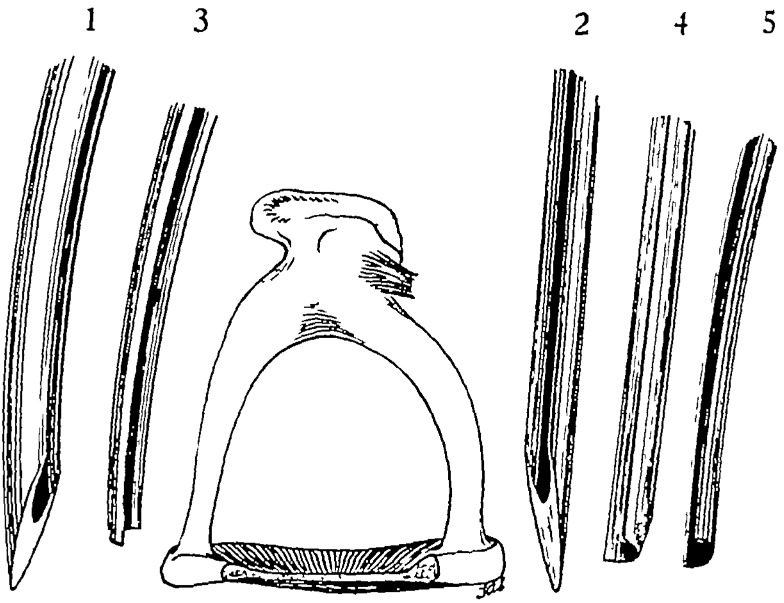

Fig 2 Drawing of normal stapes with part of footplate margin cut away to show thin central region and views of the chisel points drawn to scale and enlarged For the anterior margin of the footplate Chisel 1 (heavy curved) and Chisel 3 (light curved) are usually best suited although No 2 (heavy straight) and No 4 (light straight) may be better in some cases Nos 2 and 4 are used for the superior margin and No 5 (reverse curved) for the posterior margin

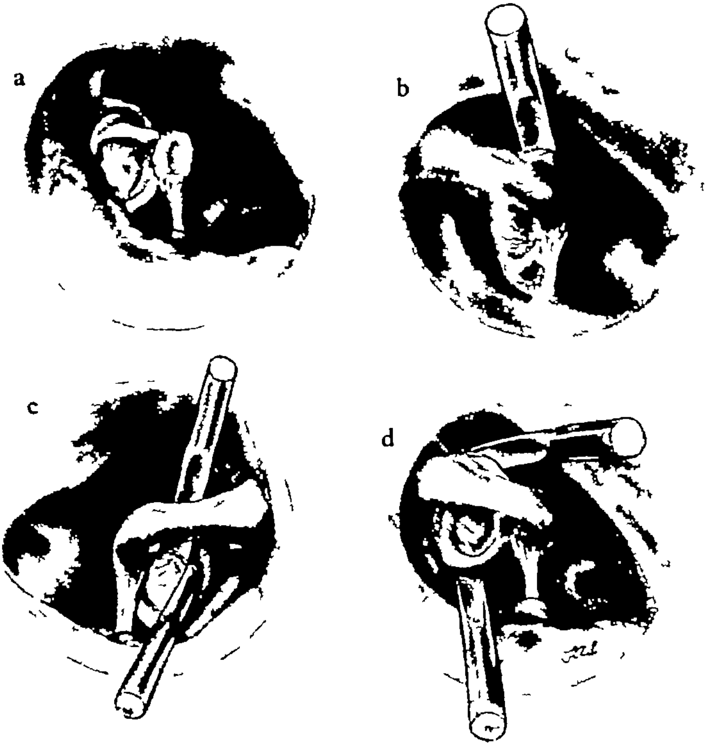

Fig 5 a. Incus removed in cadaver specimen to show anatomy of footplate region b Chisel placed at anterior margin of footplate c. Chisels placed anteriorly and superiorly d Chisels placed anteriorly and posteriorly

wield the hammer The curved chisel is best suited to the anterior margin of the footplate, although the straight ones can be used in some cases, the "heavy" model being used first until a slight movement of the stapes is seen, after which the "light" model may be used to cut the remainder of the focus With two or three light taps of the chisel, thin otosclerotic foci will be cut, and total mobilization of the stapes will be accomplished For thick and extensive otosclerotic foci the "heavy" model chisel may be used in two or three anterior locations, so as to circumferentially cut the focus Then the straight "heavy" or the straight "light"

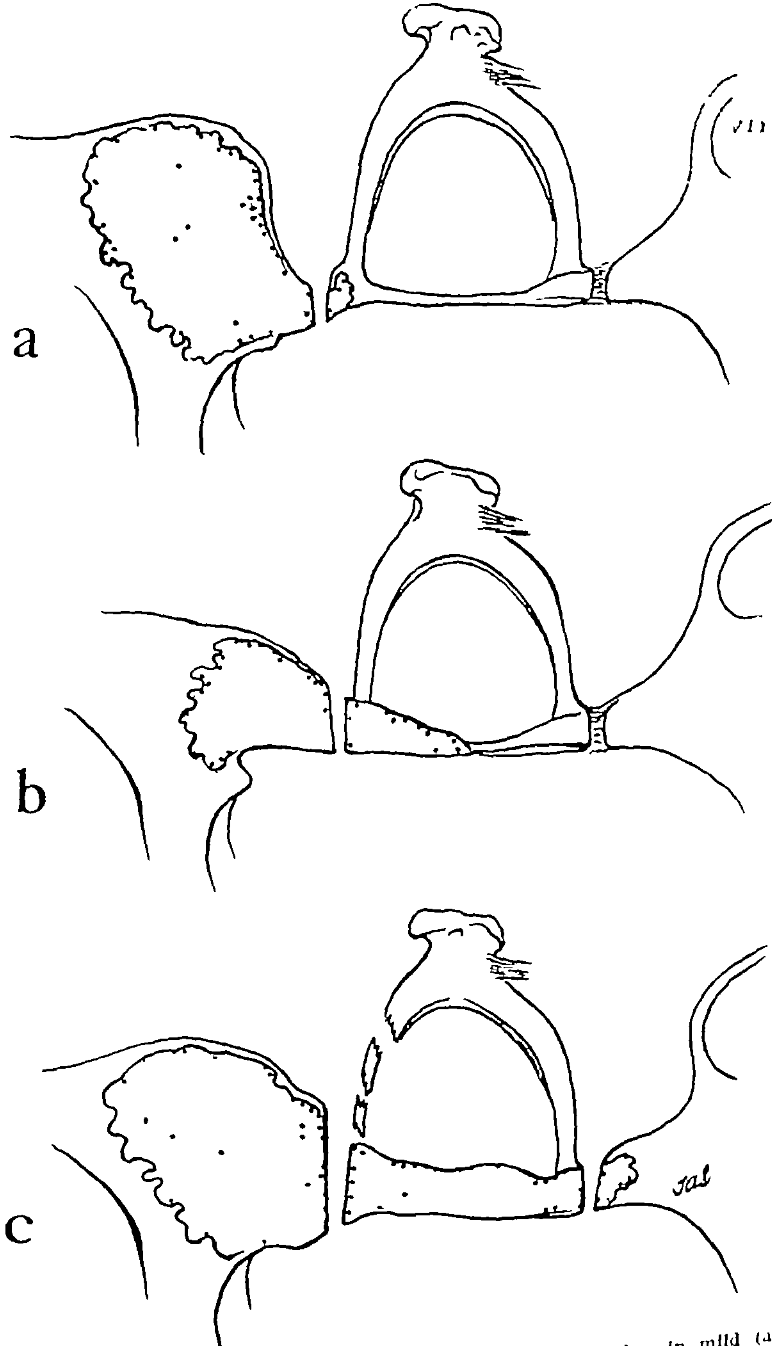

Fig 4 Objectives to be achieved in stapes mobilization in mild (a) moderate (b) and severe (c) otosclerotic lesions

nella effect The objective of mobilization in mild, moderate and severely ankylosed stapes is seen in the diagrammatic sketches in Fig 4

After the footplate is loose, a needle is inserted into the incudo-stapedial joint and rocking movements, as well as in-and-out movements, are made to insure complete mobilization of the stapes, using care not to dislocate the incudo-stapedial joint A disarticulated, or subluxated, joint should be avoided, for this might result in some hearing loss, and a few db one way or another can be critical for the patient

TABLE III

Chisel Method

| | | | |
|---|---|---|---|
| Early Results (1 month) | 144 | ears | |
| Successes | | | |
| Thresholds | 99 | 69% | |
| Bone-Air Gap | 10 | 7% | 76% |
| Improved | 20 | | 14% |
| No Change | 12 | | 8% |
| Loss | 3 | | 2% |
| Late Results (average 4 months) | 74 | ears | |
| Successes | | | |
| Thresholds | 49 | 66% | |
| Bone-Air Gap | 4 | 6% | 72% |
| Improved | 9 | | 12% |
| No Change | 10 | | 13% |
| Loss | 2 | | 3% |

Surgical audiometry, that is, hearing testing in the operating room, is employed in all operations using the Ambco Otometer In general, hearing improvement in the operating room indicated a successful mobilization, but many ears which did not improve in the operating room also had a subsequent good result We continue to use surgical audiometry but do not consider it essential for successful surgery A much more reliable indicator is the surgeon's visual and tactile impression of the state of mobility of the stapedial footplate

The most common chisel placements are shown in Fig 5 Some common otosclerotic lesions are seen in Fig 6 and were sketched by Mr Stebbins at the time of operation The

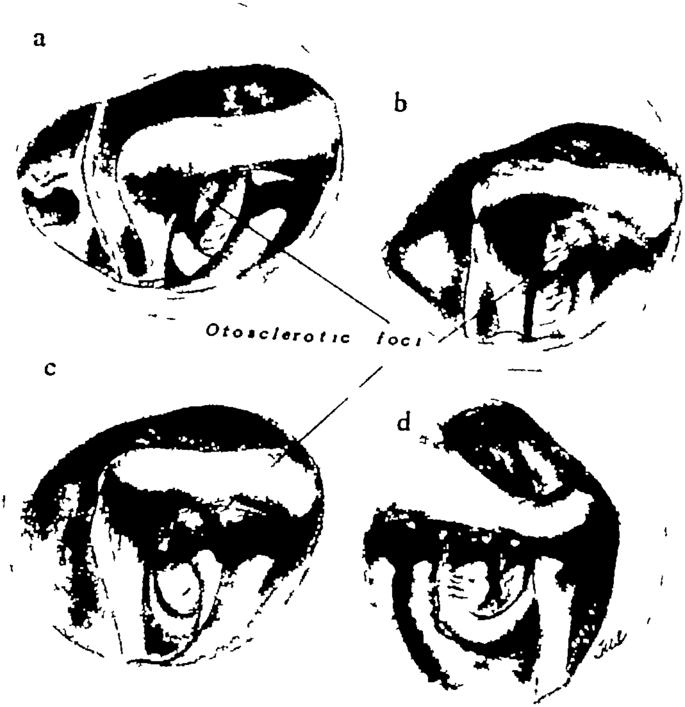

Fig 6 a b and c show moderate otosclerotic lesions as seen at operation d shows a dense otosclerotic lesion involving the entire footplate Chisel marks can be seen along both superior and inferior margin. It was impossible to accomplish mobilization in this ear There were five such cases in the total of 269

model chisel is used superiorly, and the reverse curved chisel is used posteriorly to accomplish further lysis as necessary

Occasionally there are linear fractures through the footplate when the operation is completed, but this is not serious so long as one or both crura remain intact and in continuity with part of the footplate

In ears with very thick, extensive otosclerotic foci, it is not possible to preserve the continuity of the anterior crus, but in these cases a thorough lysis of part of the footplate must be accomplished with the posterior crus providing the colum-

It is interesting to note that nine ears were re-operated and of these success was attained in six The high success rate of re-operated ears probably is because the chisel method was used in the second operation The results are summarized as follows

METHOD

| Original Operation | | Re-Operation | |
|---|---|---|---|
| Tilt | 3 | Needle | 1 |
| Chisel | 6 | Chisel | 8 |
| | 9 | | 9 |

RE-OPERATION RESULTS

| | Unchanged | Success |
|---|---|---|
| Needle | 1 | 0 |
| Chisel | 2 | 6 |
| | 3 | 6 |

## SUMMARY

The stapes mobilization operation was performed on 269 patients between October, 1954, and December, 1957 The late success rate (three months, plus) utilizing the tilt technique was 14 per cent of 22 ears, with the needle technique it was 47 per cent of 106 ears, and, with the chisel technique it was 72 per cent of 72 ears

The chisels designed by Heermann are effective instruments for mobilizing the footplate while preserving the continuity of one or both crura and maintaining thereby the columnella effect

Acknowledgments We express our appreciation to Mr Thomas Stebbins for his illustrations, and thank Mr David Shephard, Mr Dennis Bagaria and Mrs Harold F Schuknecht for their assistance in analyzing the audiometric data

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results of the chisel method are shown in Table III The chief reason why we have late results only on 74 of the 144 ears, is that 43 operations were performed less than three months before the analysis was made, and 12 patients lived out-of-town and were inaccessible An interesting difference between the chisel group and the needle group is that the percentage of late successes (three months or longer) is almost as high as the early successes (one month) The number of patients who lost their early hearing gain was somewhat less, but the main difference was that a number of patients passed from the improved to the success group after one month

## COMMENTS

The complications for this entire group of 269 operations are summarized as follows

| | |
|---|---|
| Tears of the tympanic membrane | 25 |
| Persisting perforations | 0 |
| Profound hearing losses | 2 |
| One sterile labyrinthitis, one cause unknown | |
| Otitis media (after five days) | 3 |
| Otitis externa | 4 |
| Postural vertigo | 2 |

Hearing losses were experienced in eight (3 per cent of 269 ears The cases are listed as follows

Tilt (1 of 22)

12 5 db , cause unknown

Needle (4 of 106)

15 db , pneumatic hammer

15 db , stapes depressed into oval window

15 db , cause unknown

Profound loss—initial success—loss after laparotomy

Chisel (3 of 144)

10 db , cause unknown

Profound loss, sterile labyrinthitis

10 db , footplate fenestration with removal of incus

# A GUIDE FOR STAPES SURGERY BASED ON A NEW SURGICAL CLASSIFICATION OF OTOSCLEROSIS[*]

RICHARD J BELLUCCI, M D,

New York, N Y

A better appreciation of the gross pathology of otosclerosis involving the oval window and stapes had been obtained with the introduction to otology of the surgical microscope Although the binocular loupes and headlamp were considered satisfactory at one time, it seldom was possible with this equipment to obtain a precise concept of the otosclerotic involvement or to appreciate the results of the mobilization procedure In retrospect, the mobilization operation as introduced by Rosen[1] can be considered a gross procedure which does not account for the variations in type and distribution of the otosclerotic lesion In the original description of the operation, a clear view of incudo-stapedial joint and stapedius muscle tendon was considered sufficient visualization, and the procedure simply required the application of the force to the neck of the stapes in the direction of the stapedius muscle tendon No investigation of the footplate was considered necessary, and poor visualization had to be supplemented by a keenly developed tactile sense This type of surgery produced successful results in comparatively few patients—presumably those with early and small otosclerotic lesions In the more advanced cases, both crura were often fractured before the stapes footplate could be mobilized The application of force either to the head and neck of the stapes or by the trans-incudal technique[2,3] without adequate visualization of the otosclerotic lesion at the footplate did not permit an opportunity to modify the technique according to location and degree of pathology, consequently, only cases of minimal otosclerotic involvement could be mobilized, accounting for

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[*] Read before the meeting of the Eastern Section American Laryngological Rhinological and Otological Society Philadelphia, January 9-10 1958

Editor's Note This manuscript received in The Laryngoscope Office and accepted for publication Dec. 28 1957

4 HEERMANN, H Mobilisierung des Steigbugels durch Ausmeisseln und Einwartsverlagern der Fussplatte *Ztsch Laryngol Rhinol Otol* 35 7 July, 1956

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6 PORTMANN, MICHELE Personal communication

7 SHEA, JOHN, JR Personal communication

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# PROGRAM OF THE SEVENTH INTERNATIONAL CONGRESS OF BRONCHOESOPHAGOLOGY

Meeting Place—Kyoto University, Kyoto, Japan

## Friday, September 12th, 1958

8 00 P M-10 00 P M—Reception (Party) Shimomura House in Kyoto

## Saturday, September 13th

8 00 A M—Inaugural Session (in Kyoto University Hall)

9 00 A M-12 00 M—First Scientific Session

12 00 M-2 00 P M—Luncheon (Reception The Place not decided)

2 00 P M-6 00 P M—Sightseeing in Kyoto

8 00 P M—Banquet, Miyako Hotel

## Sunday, September 14th

8 00 A M-11 30 A M—Second Scientific Session

11 30 A M-12 00 M—Closing Ceremony

12 00 M—Departure for sightseeing in Nara

1 00 P M—Luncheon, Nara Hotel

2 00 P M-6 00 P M—Sightseeing in Nara

7 00 P M—Return to Kyoto

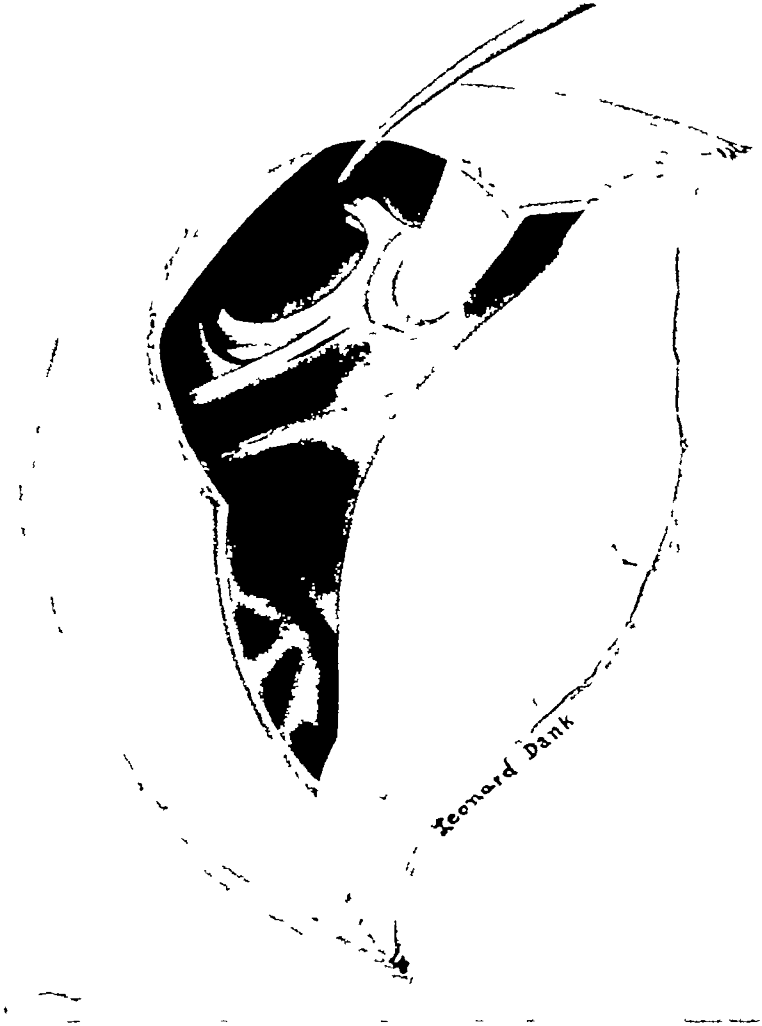

Fig 1 Class I—Early Otosclerosis Stapedio-vestibular joint space is not reduced and otosclerosis is not visible The footplate appears thin and bluish in color

structures are situated so far posteriorly with respect to the external auditory canal that the incus is not visible when the drum is reflected In these cases the bone of the posterior canal wall must be removed widely over the incus at the annulus The removal of bone in this area is a relatively the low percentage of good results obtained by these techniques

It is generally accepted that the best results are obtained when the crura of the stapes are not damaged during the mobilization procedure It is through the intact ossicular chain that sound pressure normally is transmitted to the oval window, and every effort should be made to preserve this natural route of conduction It is not rational, therefore, to fracture the crura and then attempt to mobilize the footplate of the stapes The technique of mobilization in which the forces are applied either to the head and neck of the stapes or by trans-incudinal means have now been discarded All mobilizing forces are applied directly to the point of fixation at the footplate which considerably diminishes the risk of fracturing the crura before the footplate of the stapes can be mobilized

The application of the mobilizing forces directly to the footplate had not been safe when no more magnification was available other than the loupes and headlamp With high magnification the footplate of the stapes can be manipulated under the combined sensations of touch and binocular vision making possible positive control over the mobilizing force Surgical penetration through the footplate into the vestibule during the mobilization operation rarely occurs when the stapes is visualized under high magnification, and consequently vertigo is experienced in very few cases

High magnification also permits the careful examination of the position, extent and character of the otosclerotic lesion[4] It is then possible to modify the mobilization technique according to the pathology encountered As an excellent exposure of the footplate is obtained in over 90 per cent of the cases, there are few occasions when the surgeon does not have the operation under his complete visual control With the use of the microscope, the pathology can be seen clearly, and a carefully planned course of mobilization procedure can be chosen In less than 10 per cent of the cases the field is obscured by the tortuosity and size of the external auditory canal or by the anatomical variations in the position of the oval window in the middle ear At times the middle ear

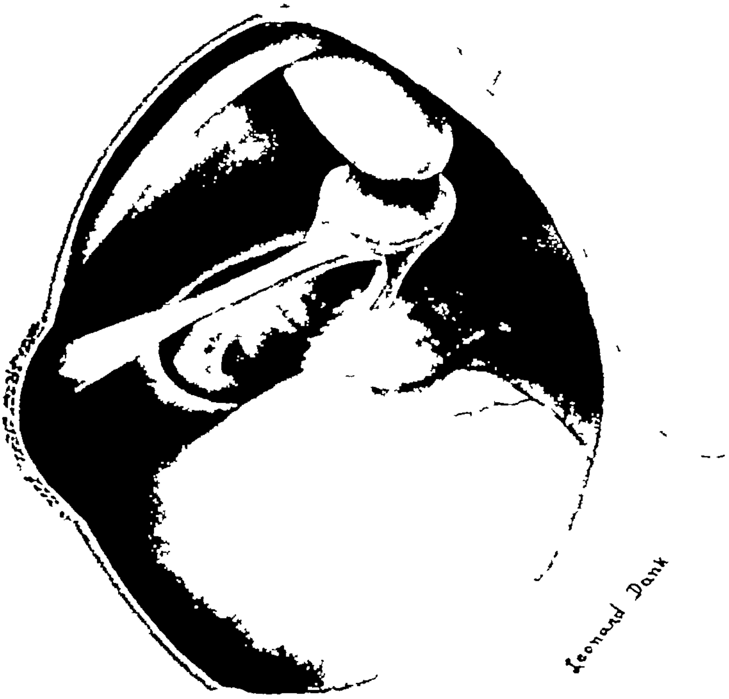

Fig 3 Class III—Advanced Otosclerosis Large otosclerotic lesion which obliterates the stapedio-vestibular joint space and involves one crus of stapes The other crus and most of the footplate are free of otosclerosis

angulation and depth of the stapes in the oval window niche can be so unfavorable that it can impose a considerable handicap to the surgeon Routinely, the mobilizing forces are applied only to those portions of the stapes footplate which are clearly seen In these unfavorable cases visualization is

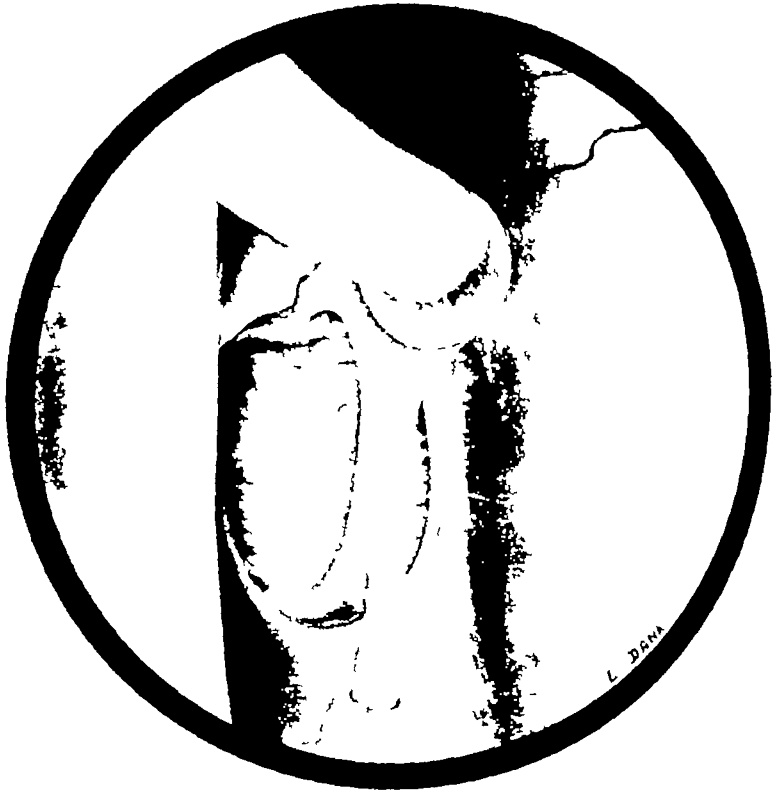

Fig 2 Class II—Moderately Advanced Otosclerosis Stapedio-vestibular joint space is bridged by an otosclerotic lesion which has advanced from the vestibular wall to the adjacent portion of the footplate The joint space is visibly narrowed but the crura of the stapes are not involved in the lesion

safe procedure and should not compromise adequate visualization of the stapedial footplate

Anatomical variations within normal limits often occur in the region of the oval window and the stapes The crura of the stapes vary in size considerably Some are extremely fragile and are injured easily The crura also may assume a variety of positions with regard to the surrounding structures Quite unfavorable for surgery is the deeply seated footplate in an oval window area which has a high lip at the promontory side or a facial nerve which overhangs the oval window impairing direct visualization (see Fig 6) The

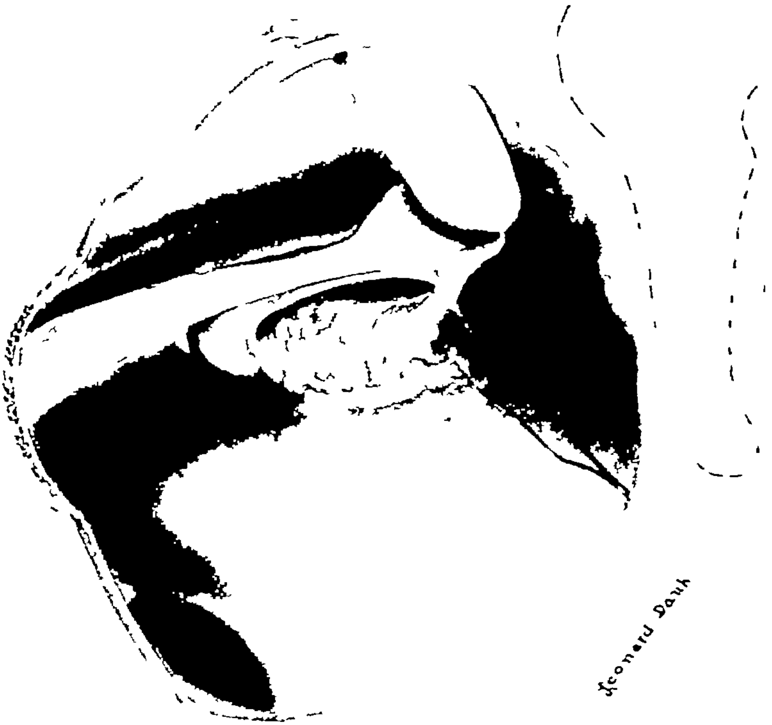

Fig 5 Class IV—Unfavorable for Mobilization Entire footplate of stapes has been replaced by otosclerosis

fixation at the stapedio-vestibular joint As the footplate normally has a slight degree of flexibility, it is possible, using light pressure of the needle, to observe slight motion of one mobile end of the footplate of the stapes when the other is fixed solidly by otosclerosis The small amount of motion obtained when the stapes is bent can be appreciated only with binocular vision under high magnification This information will direct the application of the mobilizing forces

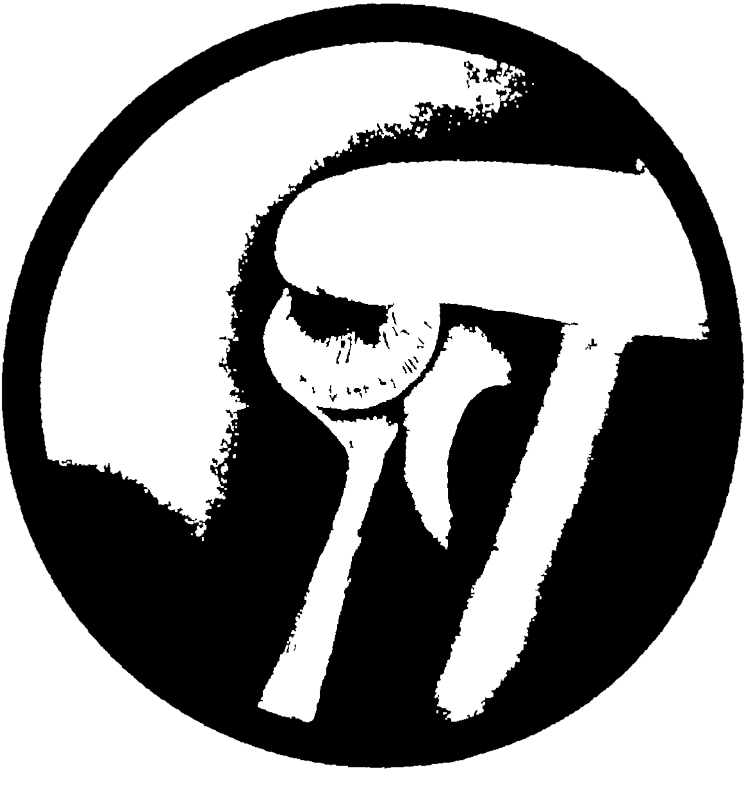

Fig 4 Class IV—Unfavorable for Mobilization Reduction of oval window niche to a narrow slit preventing adequate visualization and controlled instrumentation The facial nerve overhangs the footplate and the stapes is crowded by a large otosclerotic lesion which projects from the promontory

poor, and blind application of the mobilizing instruments on the footplate is not recommended

## PALPATION

Although adequate exposure and direct visualization of the oval window niche are important, much can be gained by careful palpation It is possible to locate the region of fixation by applying gentle pressure with a needle in orderly sequence to the incus, incudo-stapedial joint, and head and crura of the stapes Further palpation of the footplate directly will reveal information regarding the exact point of tion is considered essential in evaluating any particular case for revision

Following a successful mobilization it is possible to check the ossicular chain for continuity by observing the motion of the footplate when downward pressure is applied at the lenticular process of the incus When the ossicular continuity has been preserved, motion induced in the footplate can be seen directly and is transmitted also to the round window niche where it can be visible This provides conclusive proof that sound pressure is passing through the cochlea Less emphasis, therefore, can be placed on subjective responses and audiometry in the operating room

## SURGICAL CLASSIFICATION OF OTOSCLEROSIS

Adequate information for classification has been obtained when the exact location, nature and position of the otosclerotic lesion has been determined The selection now can be made of a mobilization technique which will be the most suitable to manage the particular type of lesion encountered When sufficient surgical experience has been obtained in recognizing the variations in the distribution and degree of involvement assumed by otosclerosis, it can be understood easily why one mobilization technique can not give a satisfactory percentage of good results In this study a higher percentage of good results has been obtained only when the technique of mobilization had been modified to meet the particular variations of the otosclerotic lesion The operation for the mobilization of the stapes at this point takes on a new character The presenting anatomy and pathology must be studied carefully and a surgical plan is formed either to circumvent the lesion when it is extensive, or to apply the mobilizing forces directly to the point of fixation causing separation through the otosclerotic lesion

Although innumerable variations occur in middle ear anatomy and in the otosclerotic involvement, certain similarities have become evident which permit a classification on anatomic and pathologic basis All cases can be catalogued within four general classes, and a surgical technique is described which is suitable to deal with each type of involvement

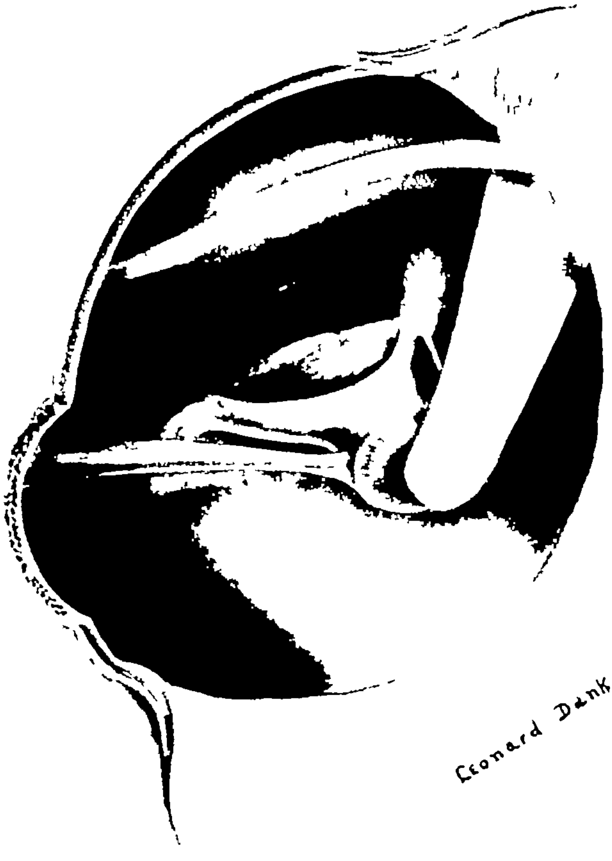

Fig 6 Class IV—Unfavorable for Mobilization Both crura are fixed by the otosclerotic lesion at the lip of the promontory The footplate of the stapes rests in a very deep oval window niche and is obscured by a prominent facial nerve

to the area involved by the otosclerotic lesion Injury to other parts of the stapes not responsible, for the ankylosis can be avoided by these means

The results of the mobilization procedure also can be determined accurately by palpation Injured portions of the stapes can be easily recognized and should be noted This informa-

2 Definite narrowing of stapedio-vestibular joint by visible otosclerosis is present The lesion usually involves a portion of the footplate of the stapes but neither crus is involved in the otosclerotic lesion

3 The usual normal blue color of the footplate has remained unchanged except for a region near the otosclerotic focus, where it is white and opaque

4 Palpation under magnification reveals solid fixation at one end of the stapes The other end exhibits slight motion

In this study, most cases of otosclerosis presented the characteristics of Class II Methods of mobilization which depend upon the strength of the crura are successful only occasionally when the otosclerotic lesion has advanced to this degree Under these conditions the crura usually are not strong enough to withstand the pressure required to free the footplate, and fractures of the crura occur often when the mobilizing force is applied to the head or neck of the stapes Application of the mobilizing force directly to the otosclerotic lesion at the footplate permits mobilization in many of these cases without the danger of losing ossicular continuity The application of pressure, depressing the footplate into the oval window, with a sharp curved needle at the base of the involved crus nearest the fixation can be an alternate means of applying the mobilizing force When this involvement is extensive, extreme care is needed to prevent penetration into the vestibule or injury to crura When attempting to achieve mobility, the otosclerotic lesion can be weakened by many re-applications of superficial needle punctures performed under direct visualization These punctures can be done safely under the control of vision and touch During this type of mobilization there is usually a fracture of the footplate or separation of the stapedio-vestibular joint with a loss of a small amount of perilymphatic fluid As the pressure has been applied only to the footplate, the crura usually remain intact Occasionally the crus nearest the otosclerotic lesion may be injured This is not of serious consequence as hearing improvement is possible when continuity is maintained between the intact crus and a mobile portion of the footplate

*Class I, early otosclerosis* has been observed in 36 per cent of cases studied (see Fig 1)

*Characteristics*

*1* Good exposure and visualization of footplate is possible

*2* No evidence of narrowing of stapedio-vestibular joint and no otosclerosis is visible

*3* The footplate of stapes is of a normal blue color, smooth and regular

*4* Palpation under magnification reveals fixation at one end of the footplate of the stapes, slight motion can be obtained at the other end

Cases with early otosclerosis, in which the lesion is very small and not visible with the microscope, are grouped in this class The otosclerotic lesion is assumed to be either entirely fibrous or containing a minimal amount of calcification Usually mobilization is accomplished easily by gentle pressure of the needle at the point of footplate fixation Needle pressure (forcing the footplate into the oval window) at the base of the crus near the stapedio-vestibular joint usually is successful when attempting to achieve footplate mobility (see Fig 1) Penetration into the joint space is rare, as the mobilizing force is under the direct control of vision and touch, and escape of perilymph also is rarely seen It is reasonable to assume that most cases which terminate successfully when the mobilizing force was applied to the neck or head of the stapes had minimal otosclerotic involvement and could be included in Class I Those cases with more advanced lesions, such as those grouped in Classes II and III would have terminated unfavorably with the early techniques, as these lesions needed more force for footplate mobilization than could be applied through the crura of the stapes

*Class II moderately advanced otosclerosis* was observed in 11 per cent of cases (see Fig 2)

*Characteristics*

*1* Good exposure and visualization of footplate is obtained to obtain a significant improvement in hearing, therefore, all efforts should be made to prevent fragmentation A crus of the stapes resting in the perilymph of the oval window without an attached portion of footplate does not perform well, and a satisfactory improvement in hearing is usually not obtained

*Class IV, unfavorable for mobilization of the stapes,* are cases with very advanced otosclerosis and those complicated by extremely difficult anatomic variations Only nine per cent of cases in this study were found to have these characteristics

*Characteristics*

*1* There is poor exposure and visualization of oval window due to extreme anatomic variations (see Fig 4)

*2* Large otosclerotic lesions may be seen, which have replaced the footplate completely with solid white bone obliterating the stapedio-vestibular joint (see Fig 5)

*3* Extensive otosclerotic lesions originating from the margin at the promontory and involving both crura are also unfavorable Included are cases with apparently normal blue footplate, but the crura of the stapes are fixed solidly at the promontory edge (see Fig 6) In these cases the footplate of the stapes lies deep in the oval window niche The stapes is tilted toward the promontory lip and otosclerosis involves both crura just below the neck

Cases with unfavorable prognosis regarding the application of mobilization procedures are grouped in Class IV These cases are considered unfavorable when the anatomy of the middle ear is abnormal, permitting neither adequate visualization nor controlled instrumentation at the footplate, the prognosis is also unfavorable when both crura are fixed by otosclerosis In these cases the footplate rests deep in the niche of the oval window, and fixation of the crura occurs usually at the lip of the promontory The footplate itself may be normal in appearance, but continuity of the ossicular chain is usually interrupted in attempting to release the fixed crura from the promontory

The technique of applying the mobilizing force directly to otosclerotic lesion at the footplate has been most successful in Class II Many of these cases would have terminated unsuccessfully with fractures of the crura if the mobilizing forces had been applied to head or neck of the stapes Application of force to the otosclerotic lesion meets the resistance at the strongest point, providing greater opportunity for successful mobilization of the stapes The difference in statistics published in 1956[7] and those reported in this study represent chiefly the accomplishments of this present technique in this class of otosclerotic involvement

*Class III, advanced otosclerosis,* was found in 14 per cent of cases studied

*Characteristics*

*1* Good exposure and visualization of footplate is present

*2* A large otosclerotic lesion involves the stapedio-vestibular joint, one crus of the stapes, and a portion of the footplate (see Fig 3)

*3* Near the otosclerotic lesion, the normal blue color of the footplate is replaced by solid white opaque bone

*4* Palpation reveals solid fixation of the greater part of the footplate, but slight motion can be demonstrated at the uninvolved end of the footplate

When a large otosclerotic lesion of this type is found no attempt is made to fracture directly through the lesion The crus is divided above the otosclerotic mass as recommended by Fowler,[5] permitting the uninvolved crus to maintain continuity with the uninvolved portion of the footplate The footplate is fractured in its midportion by multiple superficial punctures with a fine curved needle Usually there is an escape of perilymph through the fractured footplate Occasionally other lines of fracture occur with fragmentation of the footplate into several parts This is to be avoided as only a small fragment of the footplate may remain attached to the mobile crus, insufficient to permit transmission of sound pressures Approximately one-half of the footplate attached to the functioning crus has been found necessary

It is unfortunate that this decision excludes cases with weak cochlear function, as some of the most impressive results obtained by mobilization of the stapes procedures are in this group Although a remarkable improvement in hearing has been obtained following the mobilization of stapes in many patients with weak cochlear function, these cases are not represented in this statistical analysis By accepting only ideal candidates it is possible to compare accurately results obtained by the techniques presently in use with the former procedures in which the mobilizing force was applied to the neck of the stapes Considerable improvement has been found to exist when the latter group of cases is compared to the former

When the mobilizing force was applied directly to the otosclerotic lesion at the footplate, an immediate improvement (one week postoperative) in hearing to above the 30 db level was obtained in 72 per cent of cases This figure is more than double that obtained (35 per cent) when the force was applied to the neck or head of the stapes This difference in percentage occurred as the result of a reduced number of injuries to the crura of the stapes and to the preservation of the continuity of the entire ossicular chain The earlier techniques depended chiefly on the strength of the crura for mobilization of the footplate, and in most cases once the crura were fractured no further manipulation was possible The application of force directly to the point of fixation permits considerably more maneuvering and manipulation, yet preserving ossicular continuity Although the figure of 72 per cent is encouraging, failure to obtain immediate improvement in hearing occurred in 28 per cent In these cases the otosclerotic lesion was either too extensive to be safely mobilized, the anatomy of the oval window was unfavorable, or, accidental fracture of both crura occurred with loss of ossicular continuity Unfavorable anatomy and pathology accounted for nine per cent of these failures, and 17 per cent did not have a satisfactory improvement in hearing because of accidental injury to the footplate or crura of the stapes In two per cent of these cases the otosclerotic lesion also involved the round window niche

The prognosis also is considered unfavorable when the otosclerotic lesion has entirely replaced the footplate, obliterating the stapedio-vestibular joint In this study the crura were found freely movable in two cases In both a large otosclerotic mass had replaced the footplate completely and had reduced the crura to thin fibrous and flexible strands of tissue Chisels, burs and hooks used to achieve mobility or fenestration of the footplate, when completely replaced by otosclerosis, were found to expose the labyrinth to undue risks When confronted by anatomic and pathologic conditions characteristic of Class IV, mobilization of the stapes operation is not recommended, as the safety of a controlled operation is lost It is preferable to consider the fenestration of the horizontal canal, which avoids this area of excessive otosclerotic involvement and provides the technical control required for this delicate surgery House[6] agrees with this point of view Deliberate fenestration of the footplate has not been attempted as all cases in which the footplate has been fenestrated accidentally have had only a slight initial improvement in hearing which was lost within a relatively short time It is well recognized that one type of medical or surgical management cannot be ideal for all variations of a disease process This medical axiom should be applied to the stapes mobilization operation

## DISCUSSION OF RESULTS

The results obtained in a series of 100 cases, considered ideal for fenestration surgery were reported in 1956 At that time it was believed valuable to establish a baseline for the new mobilization of stapes operation performed exactly as introduced by Rosen, using candidates ideal for the fenestration operation (horizontal semi-circular canal) Attempts to represent statistically all cases acceptable for mobilization surgery, including those with weak cochlea function, yet possessing some degree of cochlea reserve, produced considerable confusion in the presentation of results, therefore, only results obtained with ideal candidates were reported in 1956 Again, in this present study of 100 cases, using the described surgical techniques, only ideal cases which satisfied the criteria for fenestration operation have been included the footplate had been achieved often by a fracture directly through a solid but active otosclerotic lesion which rarely would have occurred by the earlier techniques. The footplate techniques also create more reaction at the site of the ankylosis, possibly hastening re-fixation in some cases.

Vertigo frequently has been encountered during the operation for the mobilization of the stapes. This symptom can be induced by merely applying the aspiration tube near the round window niche, or can be caused in the process of mobilizing the stapes.

When the mobilizing force was applied to the head or neck of stapes fewer patients complained of vertigo at the time of surgery, and only 2.0 per cent experienced vertigo lasting over 24 hours. Table II presents a comparison with later cases, in which the mobilizing force was applied directly to the footplate of the stapes. Although many more patients experienced vertigo at the time of surgery, few patients continued to experience vertigo after 24 hours.

TABLE II

| Duration of Vertigo | Mobilization at Head or Neck | Direct Mobilization at Footplate |
|---|---|---|
| At Operation | 10.0% | 31% |
| Less than 24 hrs. | 3.2% | 10% |
| More than 24 hrs. | 2.0% | 6% |

These results are rather impressive, as they testify that the labyrinth is a hearty structure able to withstand surgical trauma. Vertigo as a result of shallow penetrations into the vestibule, accompanied by the loss of perilymph through a fracture in the footplate, has been observed to last several hours after surgery. Deeper penetration which may disturb the saccule or the utricle causes disturbances in equilibrium which usually terminate within a week. It also has been noted that a period of vertigo may follow an injury to the vestibular sense organs without causing a loss of hearing below the preoperative level. It has been found preferable to cover perforations of the footplate with a small piece of

It is significant to note from Table I that the application of the mobilizing force to the head or neck of the stapes produced an immediate improvement in 35 per cent of the cases. Only six per cent of these improved cases returned to the former level of hearing within a period of four months. In contrast to these figures are the results obtained with the present techniques. Although it was possible to obtain an immediate improvement in hearing in 72 per cent of the cases, 17 per cent returned to the preoperative level of hearing within four months. A reasonable explanation for this difference can be suggested as the cases which obtained a satisfactory improvement in hearing with the early techniques were those possessing small and possible fibrous lesions of otosclerosis. With this early procedure, little trauma to the stapedio-vestibular joint occurred in the process of mobilization, but it was possible to mobilize the stapes in only a relatively small percentage of cases.

TABLE I

| | Force Applied to Neck of Stapes | Force Applied Directly to Footplate |
|---|---|---|
| Number of Cases | 100 | 100 |
| Immediate Improvement | 35 | 72 |
| Improvement Maintained | | |
| One Month | 30 | 64 |
| Four Months | 29 | 55 |
| One Year | 24 | Not available |

It is reasonable to assume that all cases which would have terminated successfully by early techniques would also be successful when the mobilizing force is applied at the footplate. In this study there were many more cases from Classes II and III which required more extensive surgery at the footplate and crura before an improvement in hearing was obtained. This additional manipulation without the loss of ossicular continuity doubtlessly accounts for the higher percentage of good initial results. It appears reasonable that a larger percentage of cases would return to the preoperative level in the immediate postoperative period as mobilization of

4 The surgeon must constantly keep in mind that in the course of mobilization of the footplate, penetrations, fenestration or dehiscence produced in this structure will only add risks which may reduce the quality of the final result

5 The surgeon need not feel obliged to achieve mobilization of the footplate at any cost Cases presenting very advanced otosclerosis or difficult anatomy should be recognized as unfavorable for the mobilization operation and should be spared for fenestration of the horizontal canal

## CONCLUSIONS

The use of the surgical microscope adds considerable safety to the mobilization of the stapes operation, as it permits direct visualization of the otosclerotic involvement, better control of the forces required for mobilization and precise notation of the changes produced by the applied forces

It is possible to differentiate four classes of otosclerotic involvement on an anatomic and pathologic basis which can serve as a guide for the choice of a suitable mobilization technique In order to apply this classification to any case, careful study is necessary before mobilization is attempted This pre-mobilization evaluation, together with a suitable mobilization technique, has been responsible in producing a high percentage of good results with few complications

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162 East 71st Street

Gelfoam saturated in thrombin, as this tends to reduce the postoperative vertigo Uncovered perforations of the footplate are usaully productive of more vertigo and instability of longer duration

As experience is obtained with mobilization techniques at the footplate, vertigo is observed less frequently In the last 50 patients of a more recent series of cases only 12 per cent have experienced vertigo due to manipulation at the time of surgery All 50 patients were discharged from the hospital 24 hours after surgery without any evidence of vertigo At the present time the great majority of patients do not experience vertigo during the mobilization procedure, and when vertigo does occur it is mild and disappears before the patient leaves the operating room

## COMMENTS

Blind application of the mobilizing force to the footplate of the stapes is considered to be a dangerous and bold procedure, as penetration into the vestibule cannot be prevented by the sense of touch alone The mobilization of the stapes must be considered strictly an external labyrinthine operation in which any instrumentation penetrating deeper than the footplate exposes the end-organs of hearing and equilibrium to trauma, serous and possibly purulent labyrinthitis The objective of all techniques at the footplate of the stapes is to achieve mobility with absolutely no penetration into the vestibule and with the least possible surgical trauma

The techniques described above tend to emphasize the importance of the following aspects of stapedial footplate surgery

*1* The area of the footplate which is to receive the mobilizing force must be seen directly under high magnification

*2* All manipulation is done with extreme gentleness, slowly and cautiously until the character, position and extent of the otosclerotic lesion are appreciated

*3* When the area of fixation is located the choice of mobilization procedure is made in accordance with the four classes of otosclerotic involvement presented in this study in the left ear for the past four to five months About one week before the patient was first seen he described the left ear as feeling full It was at this time that he put his finger to the left ear and caused bleeding He immediately consulted a physician who visualized a tumor mass in the left external auditory canal and took a specimen of the mass for histological examination The patient denied any previous history of pain in the ear and was not aware of any discharge from the ear Two days before he was seen he noticed a numb sensation over the left side of his face and found that he could not completely close his left eye nor could he move the left corner of his mouth normally

Physical examination at this time revealed a middle-aged man with an obvious facial paralysis The paralysis was peripheral in type and not complete as there was still slight motion at the corner of the mouth on the left. The other positive findings were limited to the left ear There was a tumor mass occupying the inner half of the left external auditory canal and the tympanic membrane could not be visualized Roentgenological examination of the mastoids revealed minimal sclerosis of the cells of the left mastoid however no other abnormality of the left temporal bone could be identified The Weber test was strongly lateralized to the left. Pure tone audiometry revealed responses within normal limits for the right ear Losses averaging 40 db in the speech frequencies by air conduction were obtained in the left ear with good preservation of bone conduction Speech testing revealed a speech reception threshold of 40 db in the left ear with a discrimination score of 88 per cent. Histological examination of the tissue which had been removed previously was reported to show a very highly vascular malignant tumor with cells having

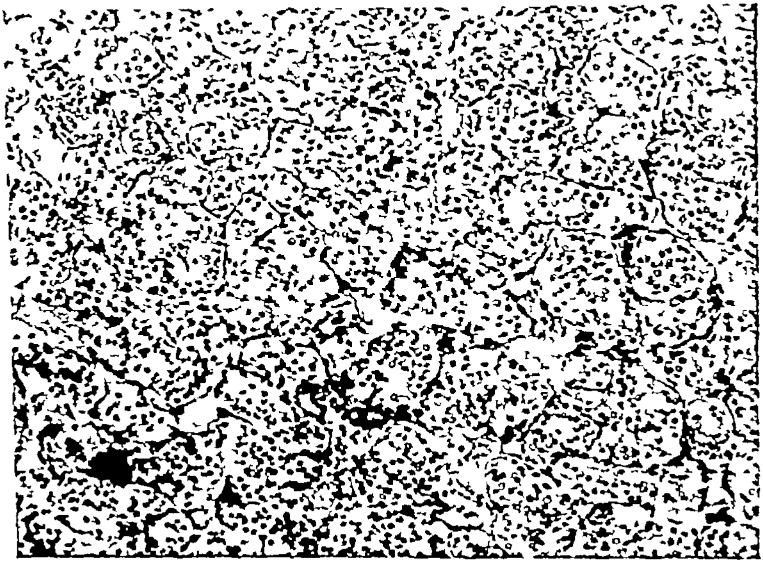

Fig 1 A representative section from a histologically benign glomus jugulare tumor showing the regular arrangement of the cells and the lack of mitotic activity

# HISTOLOGICALLY MALIGNANT GLOMUS JUGULARE TUMOR (Case Report)

GORDON D HOOPLE, M D ,
WESLEY H BRADLEY, M D ,
LEE R STONER, M D ,
and
DAVID W BREWER, M D ,

Syracuse, N Y

In the decade since Rosenwasser first correlated the clinical findings of glomus jugulare tumor with Guild's previously published anatomical description of the glomus jugulare bodies, numerous examples of this neoplasm have been reported Interest has not been limited to the otological literature alone, as excellent reports have also appeared in the journals of pathology and neuro-surgery

There has been general agreement among authors that these neoplasms should be classified as histologically benign lesions (see Fig 1) Their clinical behavior with the typical history of slowly developing symptoms, often over a period of years, would substantiate this assumption, however, their tendency to invade adjacent vital structures with the development of vascular or neurologic involvement threatening the patient's life, has led some authors to describe these lesions as histologically benign, but locally malignant by position Metastatic spread from a primary glomus jugulare tumor has been reported only infrequently[1 2 3 4]

This case report of a patient with a glomus jugulare tumor described as histologically malignant is added to the literature because of the infrequency of such a lesion

## CASE REPORT

This 49 year old white male was first seen on February 10, 1956 with a chief complaint of bleeding from his left ear of about one week's duration The present illness revealed that he had noticed increasing hearing loss

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Editor's Note This manuscript received in The Laryngoscope Office and accepted for publication May 5 1957

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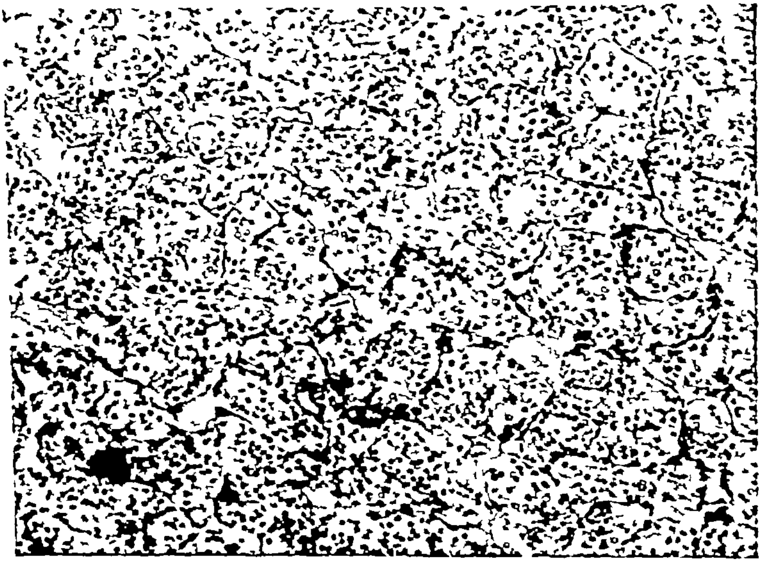

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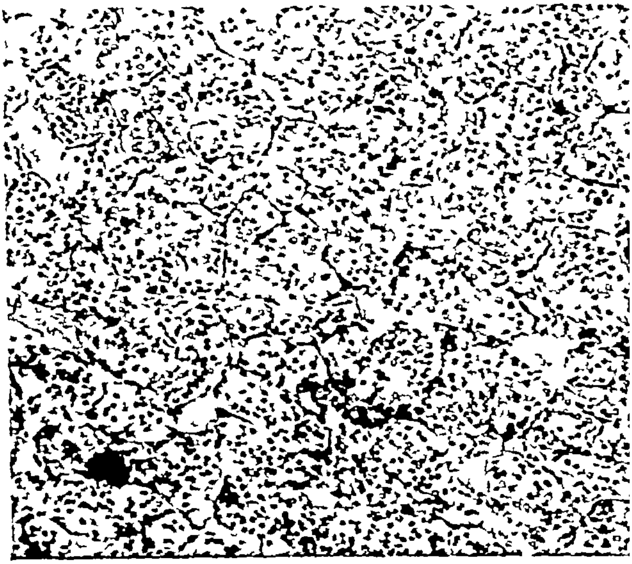

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7 The facial nerve was exposed in the anterior half of its intra tympanic segment

At the completion of surgery the cavity was relatively clean, but it was obviously realized that residual tumor had been left.

Post-operatively the patient did well and the facial paresis recovered in four days On February 24th he was started on external irradiation therapy to the left temporal bone He received approximately 3 000 roentgens over a period of three weeks

During the period of irradiation his cavity seemed to heal surprisingly well however by the time his therapy was completed a very obvious drooping of his dura had developed. Posteriorly in the bowl the dura rested almost on the facial ridge On May 2 1956 the patient had a convulsion lasting a few minutes On May 28 1956 he had a sudden hemorrhage from his left ear On June 8 1956 a return of tumor tissue in the region of the tympanum was noted On June 12 an anterior cervical node was palpated just behind the angle of the mandible. Chest X rays at this time revealed multiple metastases throughout both lung fields. His downward course following this was very rapid with increase in the involvement in the neck, the development of aphasia and finally paralysis of the right arm and leg The patient expired July 17th approximately five months after he was first seen

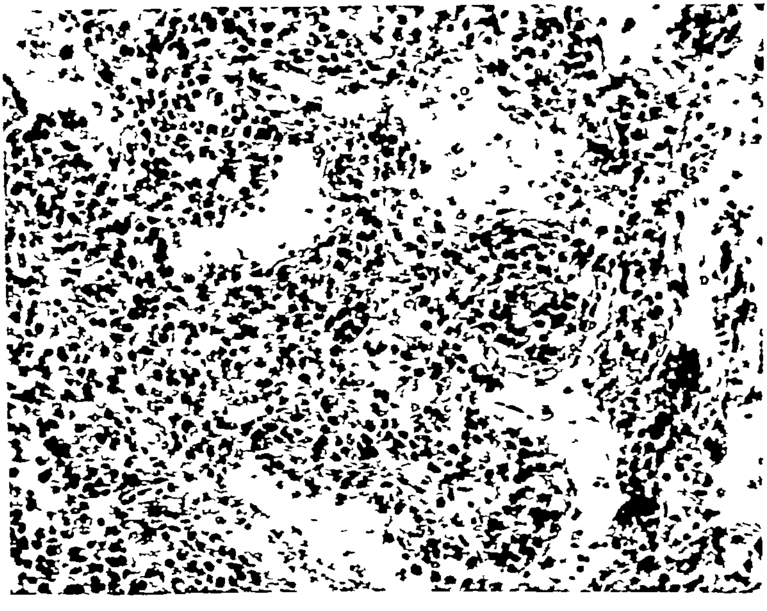

Fig 3 A representative section of the pulmonary metastases showing similar tumor tissue with a small amount of normal lung tissue still identifiable

perivascular arrangement consistent with malignant glomus jugulare tumor (see Fig 2)

On February 14 1956, left radical mastoidectomy was carried out The following interesting findings were noted at surgery

*1* There was already tumor involvement of the bone of the posterior superior canal wall with tumor tissue presenting through the bone

*2* Cells of the superior half of the mastoid were diseased and filled with tumor tissue while the cells of the lower half of the mastoid including the tip were clear

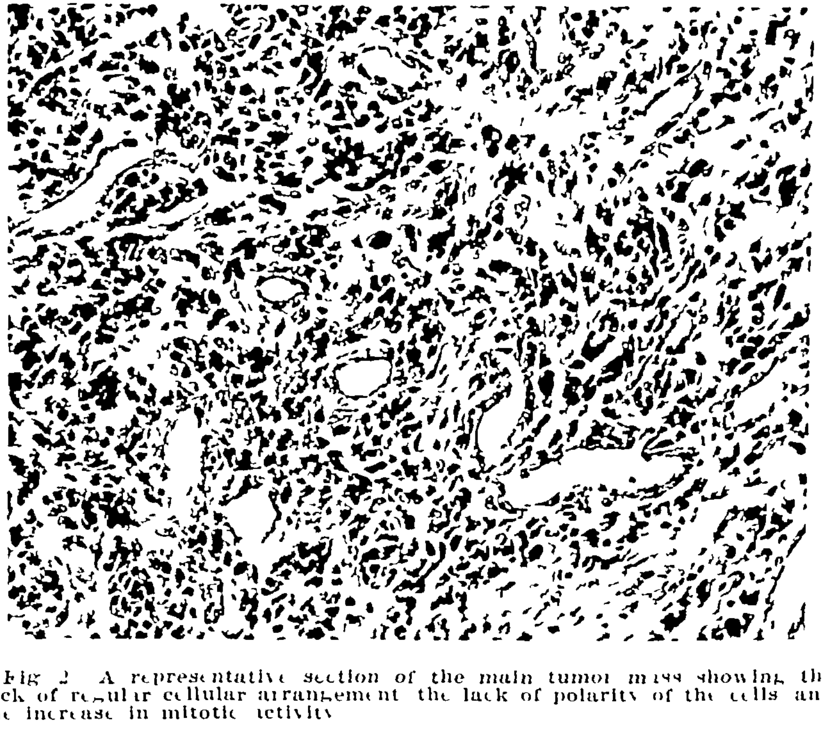

Fig 2 A representative section of the main tumor mass showing the lack of regular cellular arrangement the lack of polarity of the cells and the increase in mitotic activity

*3* The lateral sinus was pathologically exposed and there was tumor tissue on the wall of the sinus

*4* The dura was exposed over the tegmen antri for an area approximately 2 5 cm x 1 5 cm and this dura was involved with tumor tissue

*5* When the main mass of tumor was removed from the tympanum along with the remnants of the drum the stapes was visualized still present in the oval window with tumor tissue surrounding it

*6* Anterior to the labyrinth the removal of tumor tissue furnished a lead into the petrous pyramid The entire pyramid was filled with tumor tissue and the superior wall was gone leaving the dura in the area completely exposed

7 The facial nerve was exposed in the anterior half of its intra tympanic segment

At the completion of surgery the cavity was relatively clean but it was obviously realized that residual tumor had been left.

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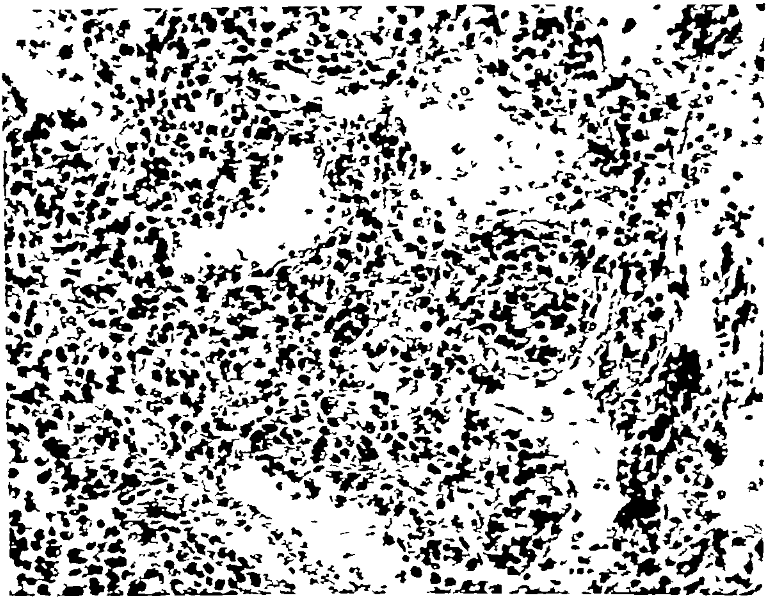

Fig 3 A representative section of the pulmonary metastases showing similar tumor tissue with a small amount of normal lung tissue still identifiable.

Post-mortem examination was carried out and revealed the following

*1* The lungs revealed multiple foci of metastatic tumor (see Fig 3)

*2* The left temporal bone and brain revealed highly anaplastic and vascular malignancy with marked infiltrative tendencies There was extension throughout the petrous portion of temporal bone with dural breakthrough Direct extension to the brain in the left temporal lobe and throughout the subarachnoid space in the posterior fossa was present

The pathological diagnosis was

*1* Malignant left glomus jugulare tumor with pulmonary metastasis

*2* Diffuse infiltration of the left temporal bone with mastoid replacement

*3* Mastoiditis and dural invasion with meningitis and direct cerebral extension

The summary of the pathologist was as follows "This rather unusual diagnosis is based on the combined pathological and clinical findings Pathologically, the topography, histology, and cytology are entirely consistent with what has been described Clinically, the localization and progression of the disease tend to confirm the findings of a primary tumor of the left temporal bone with a highly malignant potential"

## DISCUSSION

It would appear that the clinical course of this patient substantiates the histological diagnosis of a malignant lesion The rapid downhill course described above is not the typical story of a glomus jugulare tumor We have previously seen patients with equally as much or more tumor involvement who have survived without serious difficulty for a period of years, some of them with little treatment The rapid return of the lesion after surgery and its spread both locally and to distant sites are far more characteristic of a highly anaplastic squamous cell carcinoma of the middle ear

The above case history should again emphasize the fact that although these lesions are usually considered to be benign, malignant variants can and do occur With the extensive involvement which was present in this case, it was obvious that complete surgical extirpation could not be achieved Irradiation therapy did not seem to offer any additional help Whether newer techniques with irradiation therapy will offer more promising results in the future, only time can tell At this time, however, we feel we must concede that the outlook with a malignant form of glomus jugulare tumor remains pessimistic

## SUMMARY

One case of histologically proven malignant glomus jugulare tumor has been presented

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# COURS DE TECHNIQUE CHIRURGICALS

The Faculty of Medicine of Paris, Chaire de Clinique Oto-Rhino-Laryngologique under the direction of Professor A. Aubin will present a course in the Surgery of Deafness, June 9-14, 1958

# CONTROVERSIAL ASPECTS OF THE TREATMENT OF LARYNGEAL KERATOSIS[*][†]

ROBERT E PRIEST, M D ,

Minneapolis, Minn

This paper sets forth some personal experiences in the treatment of recurrent severe laryngeal keratosis, reviews the reports of others, and is written to focus attention on the problem of the treatment of severe recurrent keratosis or leukoplakia of the vocal cords In it, no attempt is made to review a large series of cases, or to draw statistical conclusions, the discussion does not pertain to mild nor non-recurrent keratosis The problem is presented from the standpoint of one clinician who is troubled by a difficult problem, of serious portent to his patients, for which only an incomplete solution exists Case summaries illustrate some of the various clinical sequences encountered, *i e*, *(a)* Keratosis with quick metamorphosis into carcinoma leading to laryngectomy *(Case 1)*, *(b)* Keratosis with long interval before becoming invasive and needing laryngectomy *(Case 2)*, *(c)* Keratosis observed for many years, treated by radiation and local excision, and after many years still apparently controlled *(Case 4)*

A recent experience in which I recommended irradiation therapy for a man having recurrent laryngeal keratosis, and the local radiologist refused to treat him, has served to make me examine carefully the various aspects and ramifications of this subject A few months ago, I removed a large keratosis from the larynx of a 74-year-old man *(Case 3)*, five years after removing a similar keratosis from his larynx The patient weighed 260 pounds, was not a good surgical candidate, and I asked his family doctor, at a considerable

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[†] From the Division of Otolaryngology of the University of Minnesota Medical School Minneapolis Minn

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distance from Minneapolis, to arrange for radiation therapy near his home I explained to the local physician that the patient's lesion was precancerous, and that I hoped that radiation would prevent later development of a cancer The local physician took the matter up with the local radiologist and others, and the collective decision was that inasmuch as the lesion was not malignant, it should not be radiated I wondered whether I had been wrong in recommending radiation for a non-cancerous lesion, and consulted with my colleagues and read what I could find on the subject, then the patient was brought to Minneapolis, where he was subjected to a full cancercidal dose of deep X-ray therapy, fractionally administered, at the University of Minnesota Hospitals Radiation

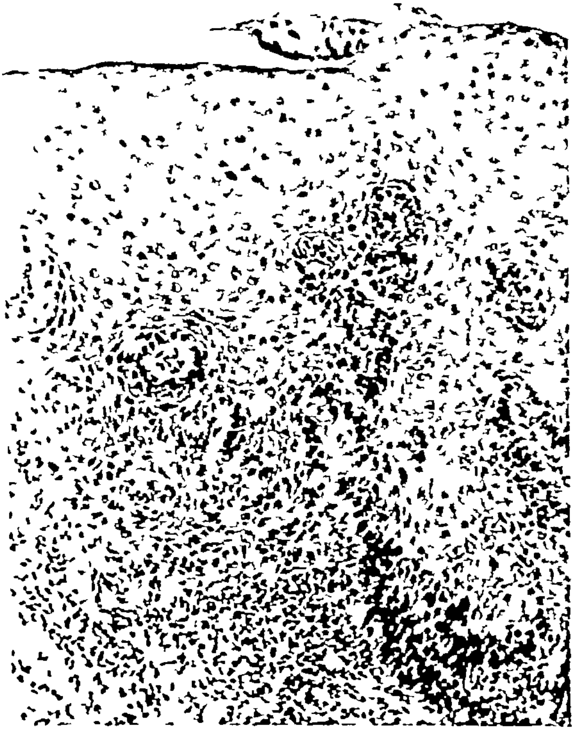

Fig 1 Case 1 Dec 7 1949 Biopsy of right vocal cord interpreted as keratosis but subsequently re-evaluated as indicating carcinoma

was prescribed here partly because of the experiences outlined below

In 1949 and 1950, I removed keratotic masses from the larynx of a 59-year-old man *(Case 1)* In 1951, a biopsy showed low grade malignancy and the larynx was removed *(Case 1,* see Figs 1, 2 and 3) This lesion progressed from

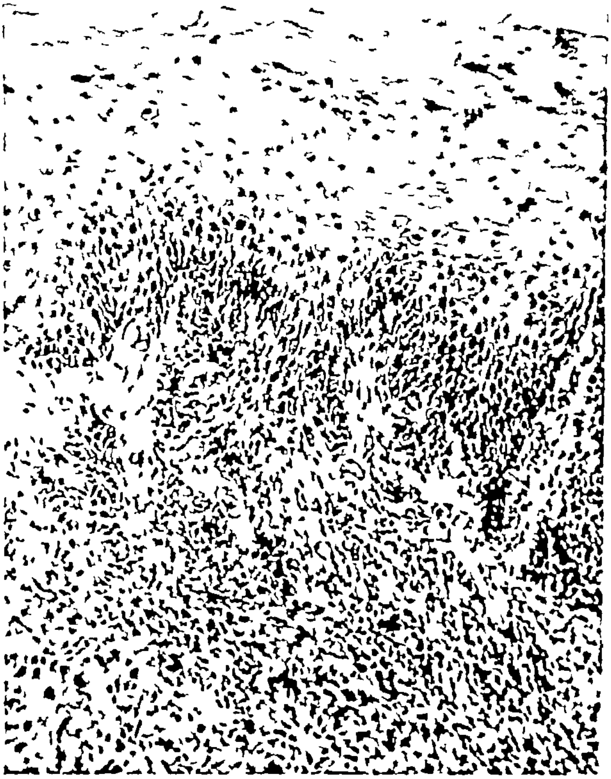

Fig 2 Case 1 Jan 11 1950 Biopsy of right vocal cord and misinterpreted as was Fig 1

keratosis to carcinoma in two years This is somewhat similar to a case cited by Jackson,[1] and is an unhappy sequence which must have been encountered by many other physicians

Shortly after this unpleasant experience another patient *(Case 2)* with an extensive laryngeal keratosis, came to me for advice This man had been told elsewhere to have a laryngectomy on the basis of a frozen section interpreted as indicating cancer My biopsy showed no cancer in the opinion of several competent pathologists (see Fig 4) I thought about the patient described above, whose keratosis I had removed repeatedly and who had developed cancer requiring laryngectomy It seemed to me that there must be a better

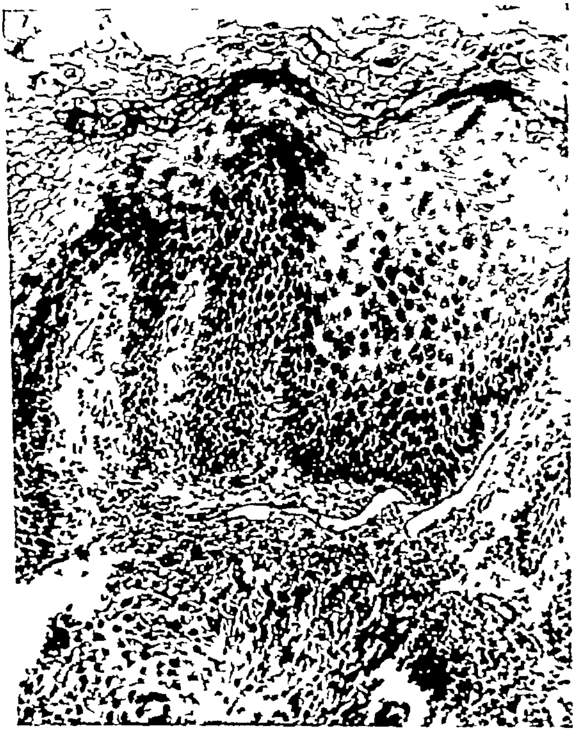

Fig 3 Case 1. Sept. 1950 Biopsy of right vocal cord misinterpreted as in Figs 1 and 2 but re-evaluated as indicating carcinoma and followed by laryngectomy with apparent cure

way to treat this condition than simply to remove keratoses repeatedly I thought that any patient who developed vocal cord cancer after precancerous lesions had been excised from his cords repeatedly, would surely have a right to wonder whether his doctor had treated him in the most effective manner It seemed that the doctor should critically examine his therapeutic method

Schall had shown that radiation produced five-year cures in 92 per cent of small cordal epitheliomas, however, I knew that radiation reduced the viability of tissues If surgery was needed later, this certainly would have to be taken into account My memory of pharyngostomes, shown to me by Dr Walter Work at The Veterans' Hospital in San Francisco, was vivid These gaping holes had resulted from poor wound healing in patients having laryngectomy after radiation had failed to cure their laryngeal cancers

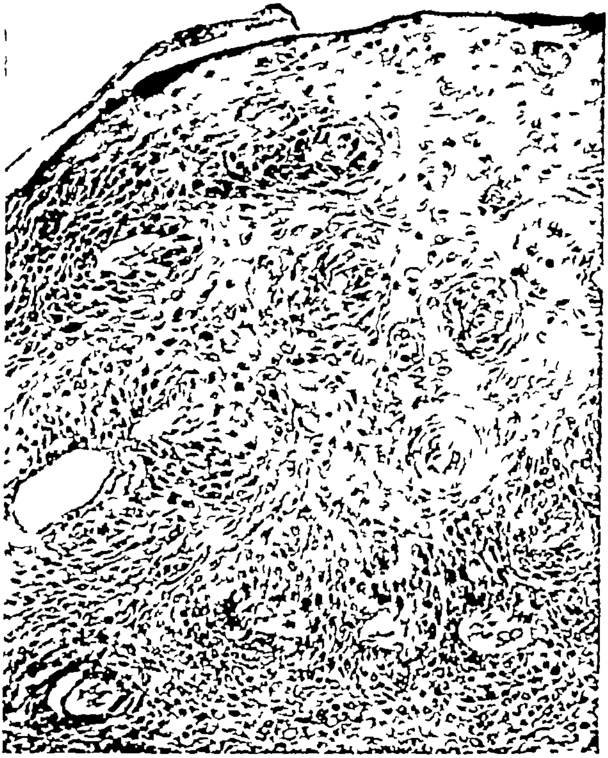

Fig 4 Case 2 July 17 1952 Biopsy of right vocal cord interpreted as indication keratosis and no carcinoma Cords then stripped of keratosis (July 21 1952) Patient subjected to repeated biopsies and X-ray therapy to larynx In 1957 biopsy showed carcinoma and laryngectomy was done

In considering Case 2, I telephoned to one of the country's most eminent laryngologists in another city and discussed the problem with him He said that he had been through the same series of experiences, and had used X-ray therapy to treat patients with recurrent laryngeal keratosis in a small number of cases with seemingly good results, therefore the patient who had been advised elsewhere to have a laryngectomy (Case 2) was treated by stripping his cords completely of keratosis, and the larynx was radiated with deep X-ray The keratosis seemed to regress, and in 1955, three years after the first biopsy, a specimen was presented at the University of Minnesota's pathologists' conference This conference is attended by pathologists from some 20 hospitals in Minneapolis and St Paul These men could see no difference in slides made in 1955 and those in 1952 They did not rule out a diagnosis of pre-invasive carcinoma, but

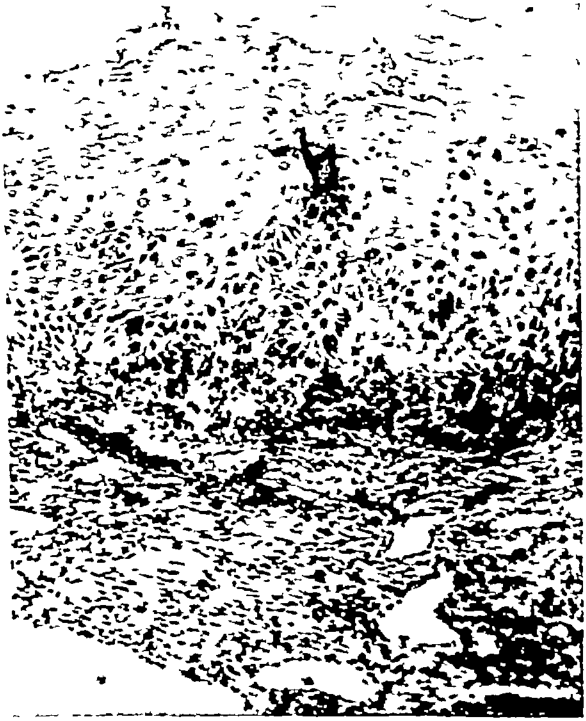

Fig 5 Case 3 July 1952 Biopsy of left cord in 69-year-old male interpreted as keratosis See Fig 6 for biopsy of same case five years later

thought one could classify the lesion as keratosis or leukoplakia with equal accuracy

From 1955 to 1957 repeated biopsies showed no change, but in 1957 an invasive carcinoma of the vocal cord was diagnosed and the larynx removed The histories of Casses 1, 2, 3 and 4 are summarized at the end of the paper and photomicrographs of their laryngeal biopsies are presented there (see Figs 1 through 9)

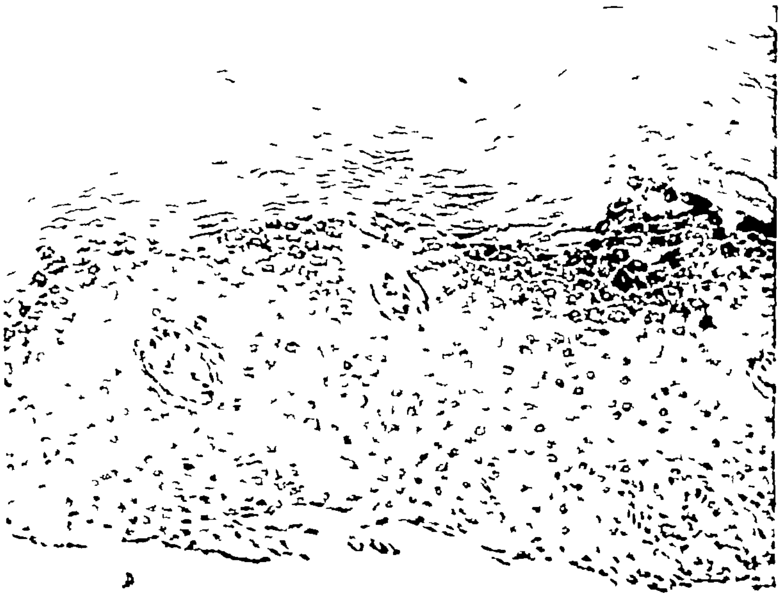

Fig 6 Case 3 April 25 1957 Biopsy of right cord for recurrence of keratosis illustrated in Fig 5 Locally excised and later treated by full cancercidal dose of deep X-ray

In treating leukoplakia or keratosis or carcinoma *in situ* of the vocal cords, the laryngologist is dependent upon the pathologist's interpretation of the biopsy and his general attitude as well as his nomenclature and classification In Case 1 cited above, the original reports by the pathologist examining biopsy specimens indicated no invasive tendency on the part of the tumor, after the larynx had been removed for cancer, re-examination of the original slides by another pathologist showed that the invasive tendency could occasionally be demonstrated (see Fig 1) It is easy for the pathologist to tell frankly invasive cells from frankly non-invasive cells in epithelial biopsies, but to be sure when the lesser degrees of invasiveness appear is difficult The sections examined cannot represent the entire specimen, and the pathologist's philosophy, astuteness, nomenclature and breadth of experience all influence his report

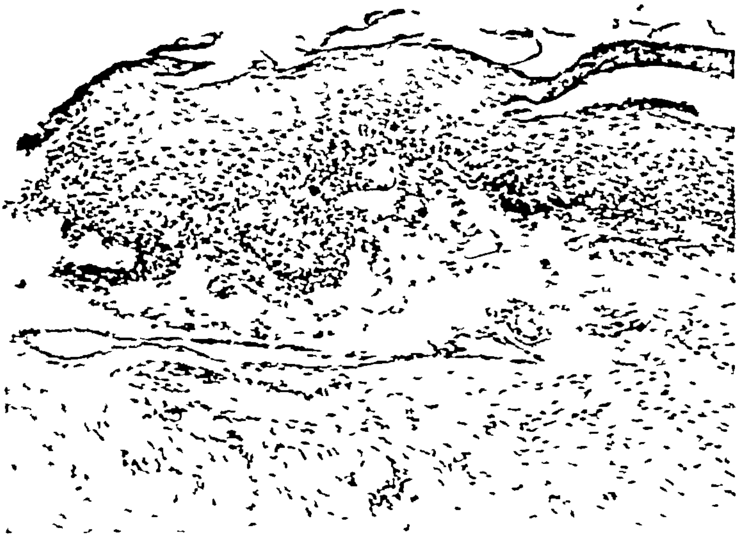

Fig 7 Case 4 1949 Biopsy of right and left vocal cords yielded tissue of this type interpreted as keratosis Deep X-ray therapy to larynx in 1952 Recurrences thereafter were limited to one small area of left cord. See Figs 8 and 9 for tissue taken seven and eight years later

Park and Lees[8] say that the pathologist, when he is at all uncertain, must play safe and make a "pragmatic" diagnosis of malignancy They cite urologic pathologists who say that intramucosal carcinoma of the prostate is present in 12 to 40 per cent of males after the age of 50 years despite the fact that the death rate from this disease is only about 1 per cent of the deaths of all males This example illustrates the present discrepancy between the morphologic definition of carcinoma and some clinical realities

The terms leukoplakia, carcinoma *in situ*, incipient carcinoma, preinvasive carcinoma, intramucosal carcinoma and superficial non-invasive intra-epithelial carcinoma are encountered in a discussion by Hertig and Younge[6] relating to carcinoma of the uterine cervix These authors say that the concept has been advanced that carcinoma *in situ* in an early stage of invasive carcinoma, and will become invasive cancer if one only waits long enough Cases are cited in which the metamorphosis occurred in 11 months to 13 years The authors admit the possibility that invasion may have been present at the time of the original biopsy, but point out that the entire cervix would have to be sectioned to decide this Thus they say "the absolute scientific proof that the *in situ* stage of carcinoma precedes the invasive stage may never be

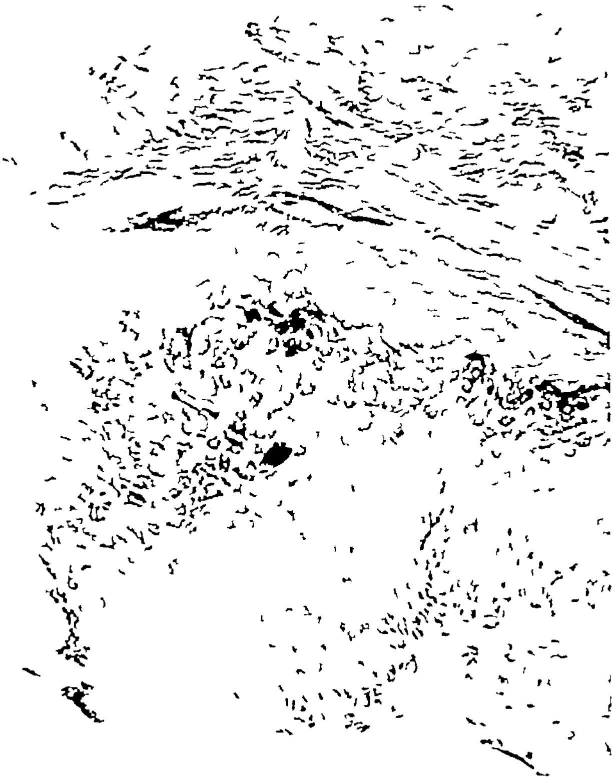

Fig 8 Case 4 1956 Similar to Fig 7

forthcoming, since to rule out early invasion one must have the entire cervix, but to prove the ultimate invasiveness of the process the cervix must be left in ”

Jones[7] described 740 patients having carcinoma of the uterine cervix Of these it was found that 13 had happened to have biopsies made one to 17 years earlier, all interpreted as being non-malignant In 12 of the 13 re-examinations of the original specimens showed squamous epithelium, and in 11 of the 12 intraepithelial carcinoma was present Jones said, “We therefore came to the conclusion that most individuals with clinical carcinoma of the cervix have a preceding lesion which we call ‘intraepithelial carcinoma’ ”

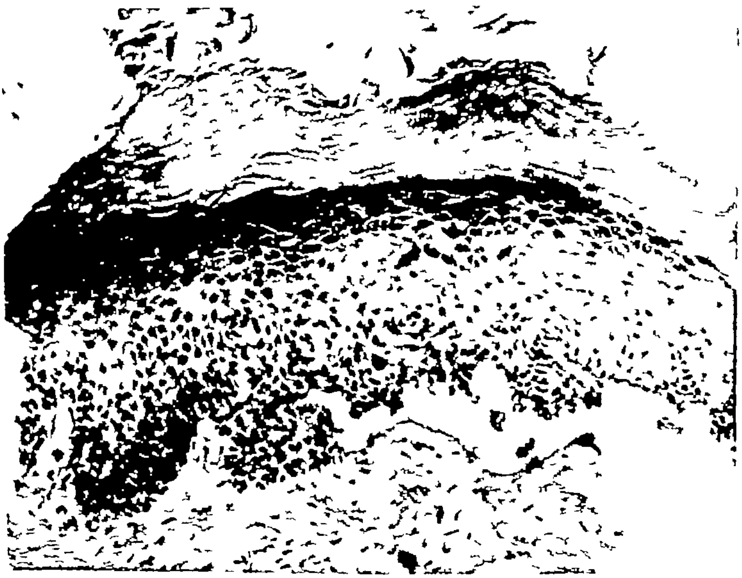

Fig 9 Case 4 1957 Similar to Figs 7 and 8 Locally removed and base cauterized with electrocoagulation

Putney and O’Keefe[3] in 1953 reviewed 125 cases of laryngeal keratosis, and said that keratosis of the larynx was a premalignant lesion in a definite percentage of cases when it persists In their cases carcinoma supervened in less than six months after the first biopsy in six cases, and only after eight to ten years in three cases, 41 never showed malignant degeneration. Putney and O'Keefe emphasize the need for repeated histologic examination of keratotic lesions of the vocal cords for accurate diagnosis. Putney[4] in 1955 commented further on these cases and others. He said that benign histologic appearance is not proof that the lesion will remain benign. He thought that management is not simple and includes forceps removal, X-ray therapy, excision by thyrotomy approach, irradiation by suspension laryngoscopy and electro-surgical removal of the lesion.

Miller and Fisher[5] feel that carcinoma *in situ* in the larynx is an early pre-invasive stage of intra-epithelial carcinoma. In their series, deep X-ray radiation was given to ten patients, the superficial lesion being stripped away in seven. In seven of the ten cases, the lesion appeared to be controlled five-and-a-half to 53 months after treatment. Recurrences after six and 16 months respectively in two patients were treated by endolaryngeal removal of the lesions without further recurrence. Two patients were treated by laryngofissure only and were still controlled 31 and 16 months later. Stripping alone was done in one patient whose larynx remained normal for 18 months. This study showed that carcinoma *in situ* of the larynx can be treated by X-ray but may recur.

*Comment.* The laryngologist treating keratosis of the vocal cord faces a complex problem. Perhaps the concept that keratosis or carcinoma *in situ* will surely become malignant if allowed to develop unchanged is true for many cases. If so, what can be done to interrupt this metamorphosis? Aside from various forms of mechanical treatment, irradiation is the most important agent available. Unfortunately, no chemical agents seem to exist at this time which upset the change of cells from the normal to the malignant state. Parenthetically, I may say here that I once treated several laryngeal squamous cancers in males with female hormones, because of the predilection of this disease for males, with no discernible result. The question of the influence of radiation therapy on *in situ* carcinoma is important. The fundamental question is: can radiation therapy influence potentially invasive epithelial cells, already morphologically different from normal but not yet different enough to be invasive, so that their invasive tendencies will be destroyed? Case 2, cited above, had the use of his larynx for six years after radiation but developed cancer despite radiation Whether his cell metamorphosis was slowed down by the radiation is a matter of opinion

The sum total of published experience on this subject appears to be insufficient to permit an absolute conclusion at this time, however, if real vocal cord cancers can sometimes be cured by radiation, when they are not far advanced (Schall[2]), does it not seem possible that recurrent leukoplakia may be discouraged in its progress toward invasive carcinoma by radiation therapy? It is reasonable to hope that in some cases malignant metamorphosis will cease or be slowed down. *The purists will argue that those cases which do not become* malignant were not really potentially malignant anyhow, and nobody can say that they are wrong Use of radiation therapy for treatment of recurrent severe laryngeal keratosis at present is empirical In severe recurrent keratosis it seems to me to be better than simple mechanical removal alone, but in cases of localized keratosis, not superior to local excision and electrocoagulation The treatment of laryngeal keratosis must be individualized in each case, and an open-minded attitude must be maintained by the clinician, to permit the use of several different therapeutic methods in any one case Radiation may be used in conjunction with local excision and/or electrocoagulation

It appears that severe recurrent laryngeal keratosis, like uterine cervical keratosis, is probably a disease extending over a period of ten or more years, in which progress from non-invasive to invasive is inevitable Frequent inspection of the larynx and repeated biopsies to detect early change from non-invasive type to invasive are essential to the management of the disease.

## ABSTRACTS OF CASES

*Case 1* A.D No 6480 aged 59 was first examined because of hoarseness in December 1949 His right vocal cord was found to be completely covered with glistening white piled up epithelium. Biopsy Dec 7 1949 was reported as benign keratosis (see Fig. 1) On Jan 11 1950, 35 pieces were stripped from cord (see Fig 2) In September 1950 he eight to ten years in three cases, 41 never showed malignant degeneration. *Putney and O'Keefe emphasize the need* for repeated histologic examination of keratotic lesions of the vocal cords for accurate diagnosis. Putney[4] in 1955 commented further on these cases and others. He said that benign histologic appearance is not proof that the lesion will remain benign. He thought that management is not simple and includes forceps removal, X-ray therapy, excision by thyrotomy approach, irradiation by suspension laryngoscopy and electro-surgical removal of the lesion.

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had recurrence of keratosis of right cord Seventeen pieces of tissue were removed from right cord and were reported as being keratosis and "no definite malignancy seen" Consultation with other pathologists indicated that malignancy was present (see Fig 3), and review of sections of previous biopsies showed that invasive tendency had probably been present all the time Laryngectomy was done on Oct 13, 1950, with apparent cure when patient was last examined in 1953

*Case 2* E D S, No 11313, first examined in July, 1952 because of hoarseness He had been advised on basis of frozen section to have laryngectomy Pearly white lesions covered all of right cord and one third of left cord On July 17, 1952, biopsy (see Fig 4), no malignancy was found On July 21, 1952 thorough stripping of cord was done Patient was subjected to deep X ray therapy elsewhere probably receiving less than a cancercidal dose because he had previous radiation for another condition in his mandible Biopsies made in 1952 were called invasive but University of Minnesota pathologists thought they were non invasive Repeated biopsies were made elsewhere and in 1957 invasive tendencies were definitely found, and laryngectomy was done elsewhere

*Case 3* F E, No 11347, aged 69 weight 260 lbs was first examined on July 19 1952, because of hoarseness, and was found to have a deep red lesion in the middle third of his left cord This was excised by direct laryngoscopy on July 21, 1952, in the belief that it was cancer Biopsy showed only keratosis (see Fig 5) The patient was instructed to return in two months He returned in five years! The lesion had recurred and had a red base and a keratotic grey surface but the cord still moved freely On April 25, 1957, local removal was done again with the mental reservation that this was cancer, and again the pathologic diagnosis was keratosis (see Fig 6) Radiation was recommended (Patient aged 74, weight 260 lbs ), and the radiotherapist in the patient's home community refused to administer it on the ground that the lesion was non malignant Patient returned to Minneapolis and full cancercidal dose of Gamma radiation was fractionally administered to the larynx in October 1957 Obviously the long term result cannot be assessed at this time

*Case 4* C W C, No 875 aged 49, was first examined in 1949 because of hoarseness Despite four weeks of vocal rest and cessation of work hoarseness persisted Gray masses partially covered each vocal cord These were biopsied (see Fig 7) and were keratosis The lesions were stripped off but recurred in 1950 and grew larger so that in 1952 deep X ray therapy in dosage just under a cancercidal dose, was administered to the larynx In 1953 a tiny keratotic plaque reappeared on the left cord This was observed through 1954 and 1955, biopsied in 1956 see Fig 8) and in 1957 was removed (see Fig 9) Histologically it was still benign keratosis Electrocoagulation of the base at the last removal may prevent recurrence, but has reduced the quality of the voice Prior to radiation the keratoses occurred all over the vocal cords After radiation recurrence was limited to one small area on one cord Obviously this man may still develop laryngeal cancer but it seems quite likely that he would have developed it long ago without treatment

## SUMMARY

Borderline malignant lesions of the larynx are discussed from the standpoints of personal experience and after review of pertinent papers The concept that the condition variously designated as intra-epithelial carcinoma, or keratosis, or carci-

noma *in situ* et al , progresses rather relentlessly from being non-invasive to being invasive over a period up to ten or more years is examined, and at least partially accepted as appearing to delineate the course of certain laryngeal lesions The similarity of behavior of laryngeal lesions and those of the uterine cervix is taken into account The possibility that Gamma radiation may be used to slow down or interrupt the progressive change of the tumor cells from non-invasive to invasive is discussed It appears that the use of such radiation, in conjunction with mechanical removal of the lesion may have value but is empirical, and its exact degree of usefulness is impossible to assess If one chooses to use radiation therapy he must take into account the possibility that wound healing in subsequent surgery may be interfered with to a substantial degree

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# ATTICOMASTOIDECTOMY IN CHRONIC OTITIS MEDIA WITH CENTRAL PERFORATION[*][†]

ROBERT HENNER, M D ,
and
COLETTE JEANTET, M D ,

Chicago, Ill

This discussion concerns itself with those patients who have persistent aural discharge due to chronic suppurative otitis media in the presence of a central perforation

These patients experience discomfort mainly of a fetid discharge, however, they are commonly considered "safe" insofar as intracranial complications are concerned These standards of safety were established early in the history of otologic surgery, and were balanced against the known incidence of surgical complications of that period Present day otologic skills in microsurgery of the temporal bone and antibiotic therapy have yielded such a high degree of success that it seems advisable to re-evaluate cases of chronic otitis media with central perforation as to their relative innocence

It should be clearly understood that all methods of nonsurgical management should first be exhausted The majority of these patients will respond to local and parenteral antibiotic therapy, as well as the time honored treatment of granulation tissue by excision and/or cauterization Adenoidectomy, when indicated, and treatment of underlying sinusitis and nasopharyngitis, whether allergic or inflammatory, particularly in younger patients, are often effective adjunctive treatment

There remains a relatively small number of patients who in spite of all nonsurgical measures, continue to suppurate, perhaps due to irreversible mastoid and attic pathology In

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[*] Read at the Meeting of the Middle Section American Laryngological Rhinological and Otological Society Inc Chicago Ill Jan 13 1958

[†] University of Illinois College of Medicine Illinois Eye and Ear Infirmary

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addition, the so-called "safety" of chronic suppurative otitis media with a central perforation refers to the only occasional presence of bone erosion by cholesteatoma in central perforation Otologists have all observed lateral sinus phlebitis, extradural abscess, facial paralysis and even brain abscess and fulminating meningitis develop after years of quiescent suppuration as the result of an acute exacerbation in the absence of cholesteatoma, also despite its low incidence, cholesteatoma does occur in a small number of such cases It may be produced by metaplasia, or a previous attic perforation may heal and with the very next acute otitis media, a permanent central perforation with chronic suppuration may result, with cholesteatoma as a surprise surgical finding Because of the potential dangers of continued suppuration, and because of the socioeconomic disadvantage of continuous and malodorous discharge, we have performed surgical treatment in many such patients

It is of interest to note that no comparable instance of a complacent attitude to chronic suppurative disease exists for lesions elsewhere in the body, especially when one considers the vital centers involved in the temporal bone area

In such patients, we have over the past 23 years, attempted radical mastoidectomy or mastoidotympanectomy While this procedure was successful in controlling the disease, the hearing response was often poor It must be borne in mind that the ossicular chain in these patients was usually intact This was in contrast to the usual improvement of hearing after mastoidotympanectomy and grafting in patients who had extensive polyposis, ossicular erosion and cholesteatoma

During this period, we also attempted atticomastoidectomy with a fenestration type flap, or the Bondy type of modified radical mastoidectomy The healing result and cessation of discharge were gratifying, but the care of the mastoid cavity became a problem When we considered the small degree of mesotympanic and hypotympanic bone necrosis, and since many of these patients are young, and because of the experience of periossicular microsurgery gained from fenestration operations, we, therefore, decided to carry out complete mas-

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weekly for 6 to 12 weeks after dusting of the cavity with antibiotic powder This is continued until the wound heals by granulations which form from the antrum to the endaural incision We have chosen to present nine out of 24 cases They are considered representative and describe the procedure and its results

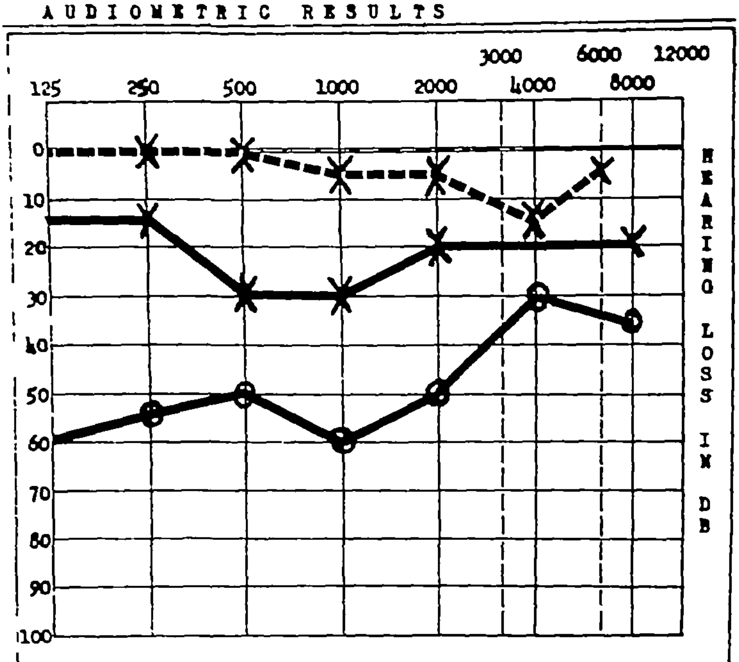


Fig. 2 D D male, Age 8, Date of Surgery 1/20/54

*Case 1*—M.A. Female age eight years first seen in November, 1952 with intermittent discharge from both ears for the past two years The family had noted some hearing loss T&A had been recently performed Examination showed severly retracted drums and evidence of secretory catarrh The child was treated repeatedly with antibiotics for recurrent episodes of pain and drainage. She underwent X ray therapy of the nasopharynx and a second adenoidectomy The right ear responded to these treatments and the hearing improved but the left ear developed a posterior and superior perforation with persistent discharge and averaged a 20 db loss

July 30 1953 an atticomastoidectomy was performed The mastoid showed mixed sclerosis and patches of granulation tissue with small areas of bone necrosis Under magnification granulation tissue was retoidectomy, including atticotomy, with careful skeletonization of the labyrinth, dural plate and ossicular chain This procedure is essentially an extensive simple mastoidectomy with addition of a complete atticotomy, preserving the posterior and superior bony canal wall It is performed endaurally so as to provide continuous access to the antrum for dusting with antibiotic powder postoperatively If granulations of the hypotympanum and peritubal area are present, a 2 mm polishing bur is spun through the central perforation inferiorly and anteriorly toward the Eustachian tube At the time of surgery, the cavity is dusted with surgical aureomycin powder and the endaural incision closed with a polyethylene drain which leads to the antrum The drain is replaced

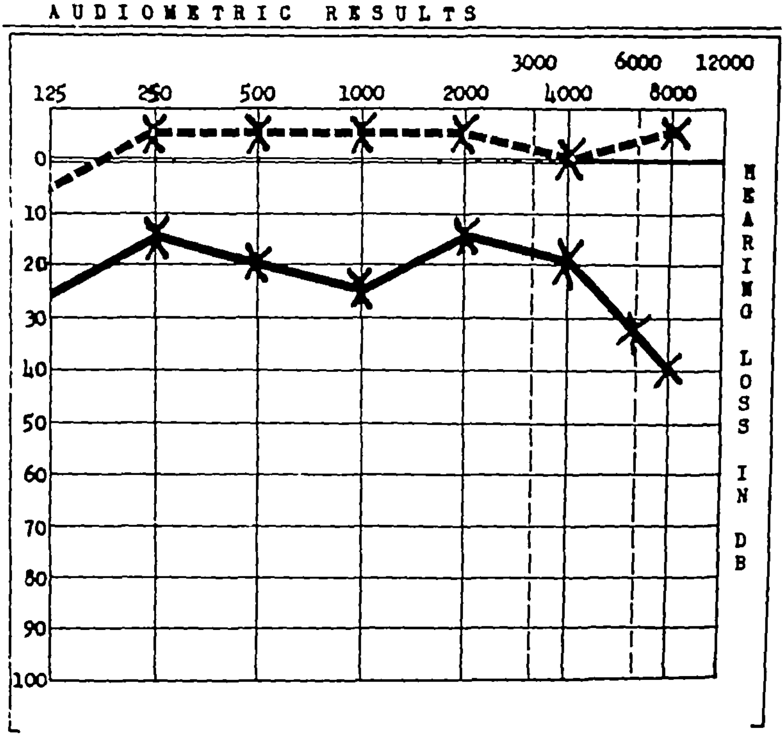


Fig 1 M A female, Age 8, Date of Surgery 7/30/53 Solid lines indicate preoperative hearing Dotted lines indicate postoperative hearing

tip and the retrofacial area These were filled with granulation tissue The attic was exposed and granulation tissue was dissected from the ossicles At the end of February 1954, the ear was healed and the hearing was practically normal by March 1954 The perforation closed spontaneously (Audiogram, see Fig 2)

*Case 3*—R. B Male age 23 first seen in March 1955, complaining of intermittent discharge from the left ear since childhood Examination showed a posterior central perforation with purulent drainage on the left side The patient had recently been treated extensively with antibiotics with each course of therapy the perforation would close and secretory otitis would ensue Paracentesis would be followed by a persistent discharge, again he was treated with antibiotics When this process had occurred four times with a hearing loss fluctuating around 30 to 35 db surgery was advised X rays of the mastoid revealed a marked disturbance of pneumatization one could see several medium sized clouded cells with thickened walls

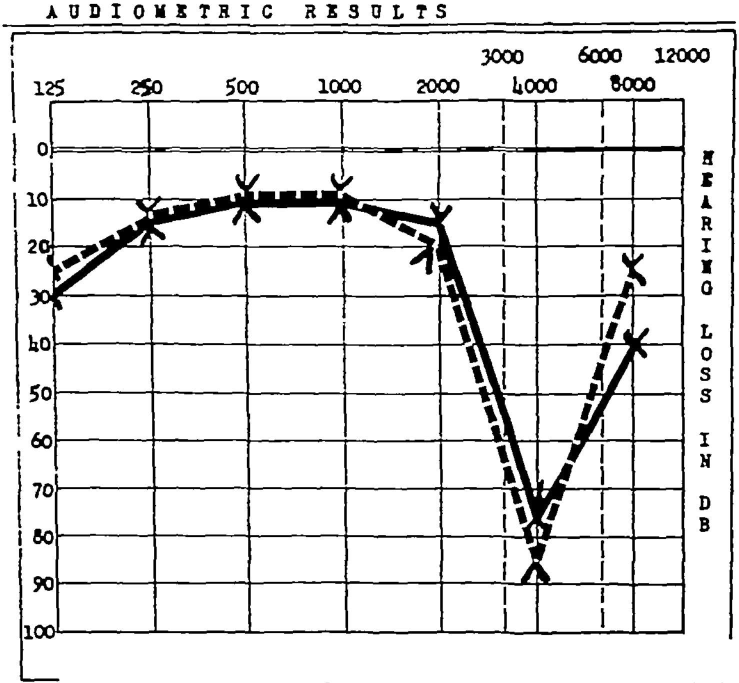


Fig 4 A. W female, Age 19, Date of Surgery 9/1/55

On March 29 1955 an atticomastoidectomy was performed There was necrosis of the mastoid cells and pus escaped under pressure Extensive granulations were found in the attic a periossicular dissection was carried out the tympanic perforation was freshened with a 1 mm.

moved from the attic and the ossicles were exposed and thoroughly cleaned

In September, 1953, healing was complete and hearing had returned to normal and has remained well (Audiogram, see Fig 1)

*Case 2*—D D, Male age eight years, first seen in October, 1953, with a history of bilateral ear infection at two months of age treated successfully with paracentesis and penicillin Three years prior to the first visit a recurrence of the infection had been again treated with penicillin followed by T&A but the left ear had continued draining intermittently ever since Examination showed a posterior central perforation of the left tympanic membrane with a protruding granuloma and purulent discharge The perforation healed after removal of the granuloma and local dusting with aureomycin powder, but the infection recurred in December 1953 again it responded well with local therapy only to flare up once more in January 1954 X rays showed a slightly underdeveloped left mastoid with patchy sclerosis and retrofacial and tip cells Hearing averaged 25 db loss in that ear Restoration of hearing was most important in this ear because of a congenital conductive loss of 30 db in the right ear

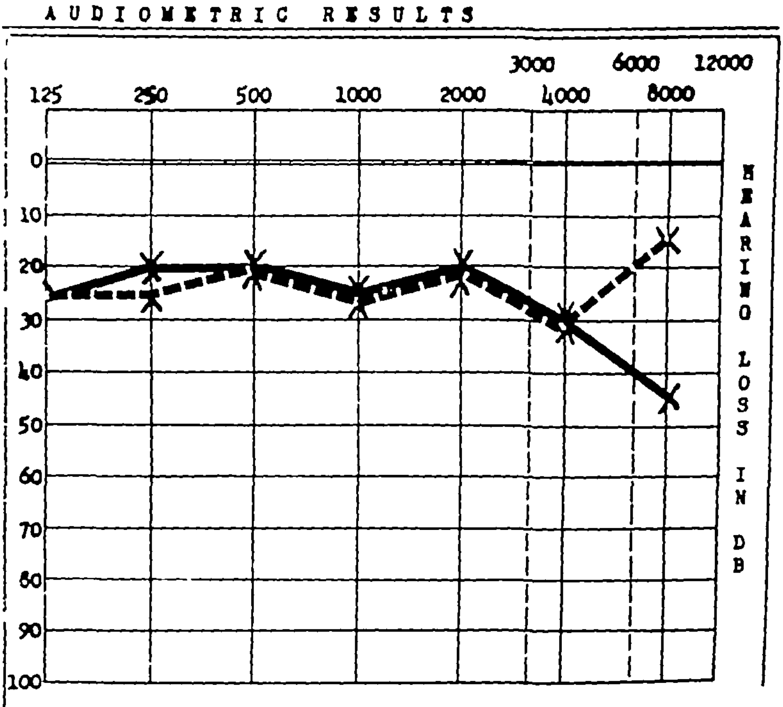


Fig 3 R B. male, Age 23, Date of Surgery 4/1/55

On January 20 1954 an atticomastoidectomy was performed The mastoid showed mixed sclerosis and cells were found only in the mastoid

*Case 5*—J A., Female, age 41, first seen in June 1956 with a history of repeated ear infections on the left side since 1927, the ear had been draining constantly for the past year The patient was complaining of headaches and tinnitus, repeated courses of antibiotics failed to cure the disease and her hearing loss averaged 40 db in the left ear

X rays *of the mastoid* showed *a sclerosing mastoid bone* and a few large cloudy perisinusal cells with thickened walls

An atticomastoidectomy was performed on July 10 1956 Chronic mastoiditis granulations of the attic and a pea sized cholesteatoma of the anterior attic recess were found and removed, the intact ossicles were left in place Healing was complete in September 1956 Post operatively her hearing improved to a 25 db level for the speech frequencies there has been no evidence of recurrence of the cholesteatoma and the patient will shortly undergo *tympanoplasty* (Audiogram see Fig 5)

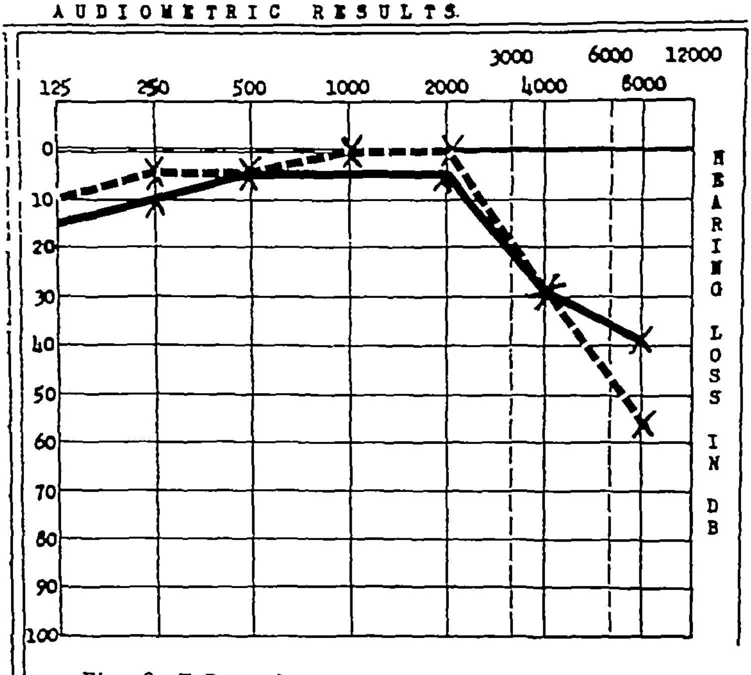


Fig 6 T R male, Age 11, Date of Surgery 1/16/57

*Case 6*—T R Male age 11 first seen in September 1956 with a history of intermittent discharge *from* both ears *for* the past eight years repeated antibiotic treatment had been unsuccessful, the adenoids had been twice removed Examination showed central perforations of both tympanic membranes with a purulent discharge the right ear responded to prolonged penicillin therapy (several courses of three to four weeks), polishing bur and closed with the triangular skinflap obtained from the endaural incision

May 27 1955 the drain was permanently removed in June the ear was dry and healed, the hearing averages 20 db (Audiogram see Fig 3)

*Case 4*—A W, Female age 19, first seen in August, 1955, complaining of intermittent pain and discharge from the left ear for several years Examination showed a granuloma on the posterior margin of the left drum with a purulent discharge and desquamative debris, several weeks of local and parenteral antibiotic care did not affect the persisent purulent discharge

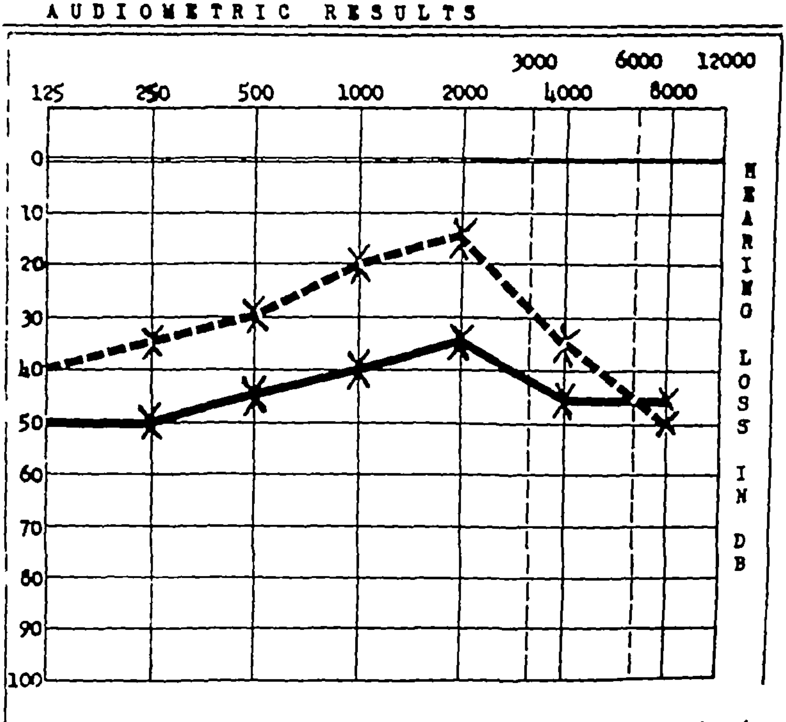


Fig 5 J A female, Age 41, Date of Surgery 7/10/56.

X rays revealed a sclerotic mastoid no isolated cells could be outlined her hearing averaged a 10 db loss for the speech range in this ear

Atticomastoidectomy was performed Sept 1, 1955 The ossicles were freed from a mass of granulations and left undisturbed The hypotympanum and peritubal granulations were removed with a polishing bur through the central perforation by the end of October the ear was dry but the perforation was still present In August 1956, the patient developed an acute infection of the operated ear following swimming The infection subsided under tetracycline therapy and the ear has been dry since Her hearing has returned to the preoperative level the perforation has persisted (Audiogram see Fig 4)

X rays of the left mastoid revealed patchy sclerosis with the exception of a few large clouded cells in the perisinus region, her hearing loss averaged 15 db An atticomastoidectomy was performed June 4 1957 Extensive granulations were found in the mastoid which was partially sclerosed, the few remaining cells contained a yellowish tenacious mucus, the granulations extending into the attic were dissected from the intact ossicular chain Our previously described postoperative care was given and in August the ear was dry currently an attempt is being made to close the perforation with trichloracetic acid applications and patching her hearing loss is 5 db (Audiogram, see Fig 7)

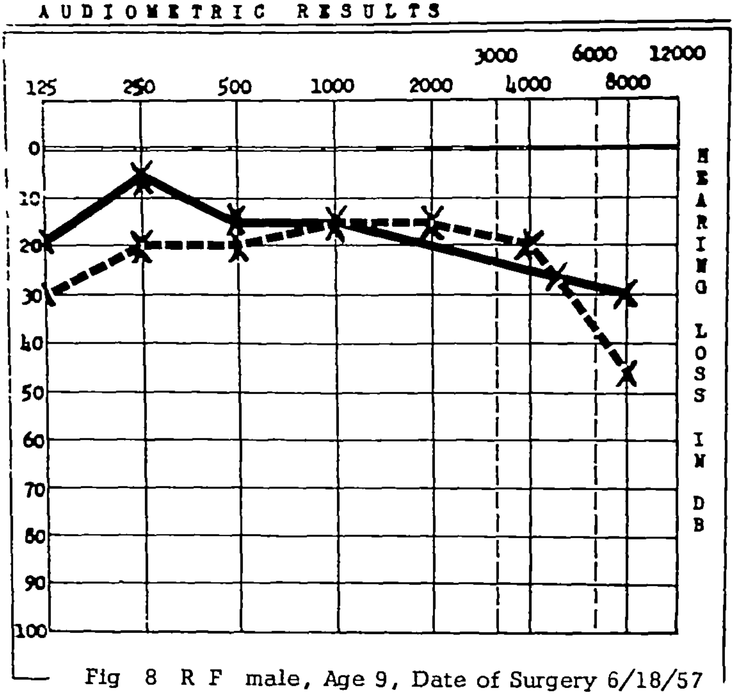


Fig 8 R F male, Age 9, Date of Surgery 6/18/57

*Case 8*—R F Male age 9 first seen in June 1957 with a history of an infection of the left ear when he was 3 years old resulting in a perforation with intermittent drainage the discharge became profuse several weeks prior to this first visit, although the patient had been on daily penicillin therapy for three years because of an erroneous diagnosis of rheumatic fever, the doses of penicillin had been increased and other antibiotics were added but failed to control the infection Examination of the left ear revealed a purulent exudate from a central perforation of the tympanic membrane. The hearing loss averaged 15 db in the speech range. X rays of the mastoid revealed a large cavity due to the confluence of several larger cells The trabeculation in the periantral region was indistinct with partial interruption and decalcification but the left ear continued draining, he was placed on sygmamycin therapy for two weeks without success

X rays of the left mastoid showed a disturbed pneumatization with lack of aeration, his hearing loss averaged 5 db in this ear On January 16, 1957, a left atticomastoidectomy was performed Granulations were removed from the perilabyrinthine area and the epitympanum On March 25, the drain was permanently removed and the middle ear has remained dry since A spontaneous closure of the perforation occurred in July There still was a dry perforation of the opposite drum this closed with trichloracetic acid applications The hearing in both ears now shows no loss (Audiogram, see Fig 6)

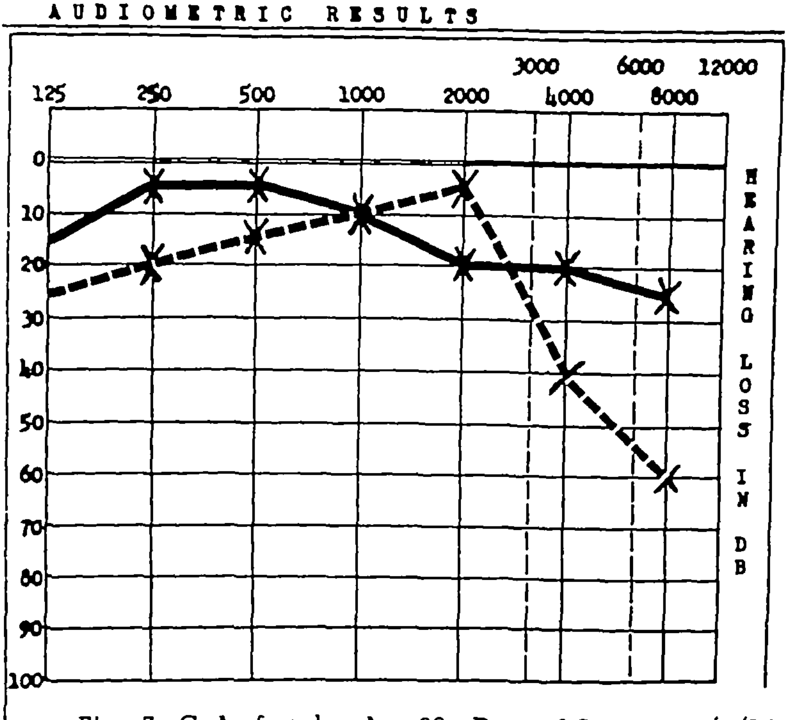


Fig 7 G A. female, Age 38, Date of Surgery 6/4/57

*Case* 7—G A Female age 38 first seen in February, 1957 with a history of bilateral ear infection at the age of 3 followed by a chronic discharge from both ears and a right mastoidectomy at the age of 19 This resulted in complete healing of the right ear, but with a residual hearing loss of 10 db The left ear had been draining intermittently and the patient had been aware of a recent increase of hearing loss on that side Examination showed a healed perforation of the right drum and a thick injected tympanic membrane on the left side with a small posterior central perforation and a mucopurulent discharge the infection responded well to prolonged tetracycline therapy but recurred shortly after cessation of the antibiotic

X rays of the left mastoid revealed patchy sclerosis with the exception of a few large clouded cells in the perisinus region her hearing loss averaged 15 db An atticomastoidectomy was performed June 4 1957 Extensive granulations were found in the mastoid which was partially sclerosed the few remaining cells contained a yellowish tenacious mucus the granulations extending into the attic were dissected from the intact ossicular chain Our previously described postoperative care was given and in August the ear was dry currently an attempt is being made to close the perforation with trichloracetic acid applications and patching her hearing loss is 5 db (Audiogram see Fig 7)

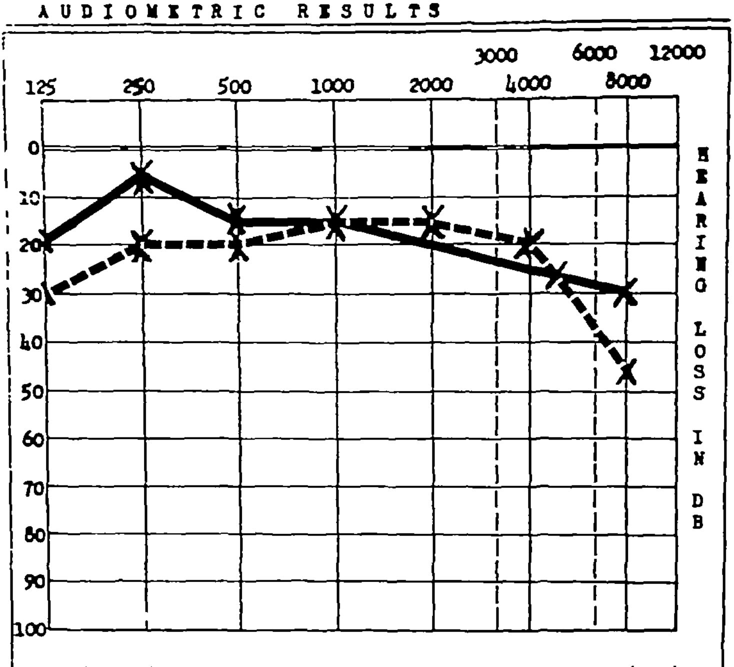


Fig 8 R F male, Age 9, Date of Surgery 6/18/57

*Case 8*—R. F, Male age 9 first seen in June 1957 with a history of an infection of the left ear when he was 3 years old resulting in a perforation with intermittent drainage the discharge became profuse several weeks prior to this first visit, although the patient had been on daily penicillin therapy for three years because of an erroneous diagnosis of rheumatic fever the doses of penicillin had been increased and other antibiotics were added but failed to control the infection Examination of the left ear revealed a purulent exudate from a central perforation of the tympanic membrane. The hearing loss averaged 15 db in the speech range X rays of the mastoid revealed a large cavity due to the confluence of several larger cells The trabeculation in the periantral region was indistinct with partial interruption and decalcification

June 18, 1957, an atticomastoidectomy was performed In the mastoid process a large confluent area of necrosis was found The entire periantral, perilabyrinthine areas and dural plate were necrotic and covered with granulations After dissection and removal of the disease the ossicular chain was found intact In September, 1957, the ear was dry with a remaining central perforation, the hearing was comparable to the preoperative findings the postoperative hearing loss in this ear averages 15 db (Audiogram, see Fig 8)

*Case 9*—D B, Male, age 10, first seen February 7, 1957, with a left acute subperiosteal mastoid abscess, temperature 101° F, and a discharging left ear, no landmarks could be seen because of the swelling His parents and the referring physician gave a history that one year prior to his present illness he had an acute ear infection treated with antibiotics which resolved without perforation or drainage

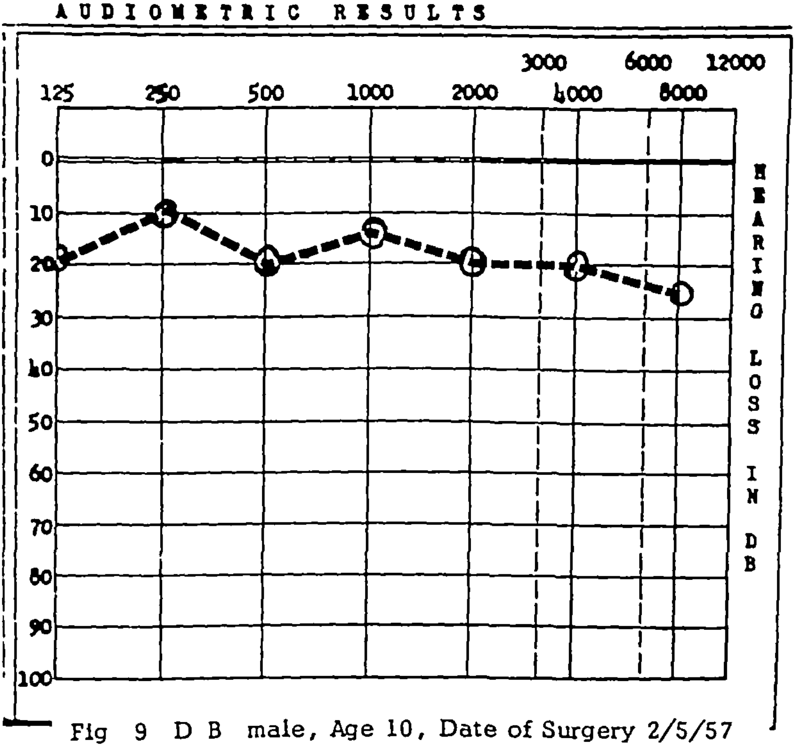


Fig 9 D B male, Age 10, Date of Surgery 2/5/57

There was no intervening difficulty until two weeks prior to admission when he developed pain in the left ear and a spontaneous discharge He was immediately placed on penicillin therapy and when this did not control the disease terramycin 750 mgms daily was added February 1, 1957 In spite of this treatment the patient developed a swelling over the left mastoid region on February 5 1957 while on the combined antibiotic therapy

X rays showed some clouding of the mastoid with some coalescence of the trabeculae

An atticomastoidectomy was performed on February 7 1957 There was extensive breaking down of the mastoid cells granulations covered the dural plate and a perisinus abscess was present, a cholesteatoma had eroded the lateral attic wall, the cholesteatoma matrix was completely removed under magnification, the intact ossicles and the remaining posterior superior canal wall were preserved a polyethylene drain was placed in the antrum and the incision was closed The ear was dry in one month, and at the present the previously unseen posterior superior perforation is healed and the hearing loss averaged 20 db on December 20, 1957

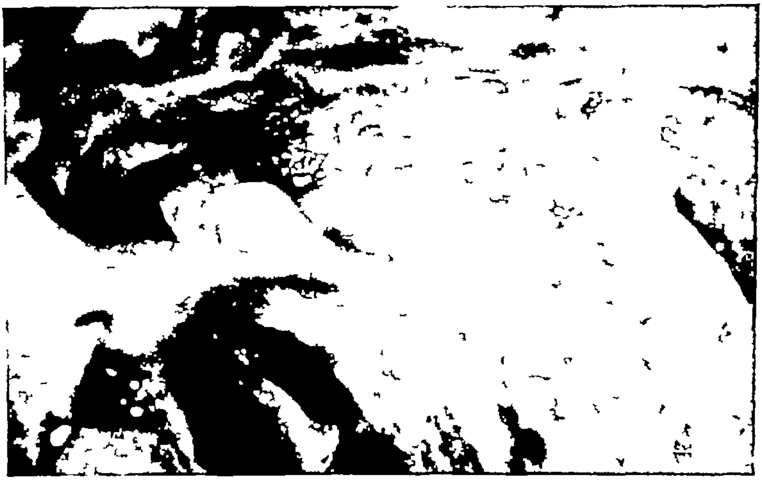


Fig 10 Photograph of surgery showing complete dissection of the anterior and the superior attic spaces and complete mastoidectomy The ossicles have been dissected free of all granulation

This case was included because along with Case V a small anterior attic cholesteatoma was found and removed through the atticotomy approach if a usual antrotomy had been performed the cholesteatoma would have been overlooked (Audiogram see Fig 9)

## PATHOLOGY

*Gross* The usual findings are a dense cortex with patchy sclerosis in a previously pneumatized mastoid process There are isolated areas of trabecular necrosis along with osteogenetic thickening in other areas The areas most prone to bone necrosis are the perilabyrinthine cells and the dural plate, particularly in the area of the tegman antri, and attic

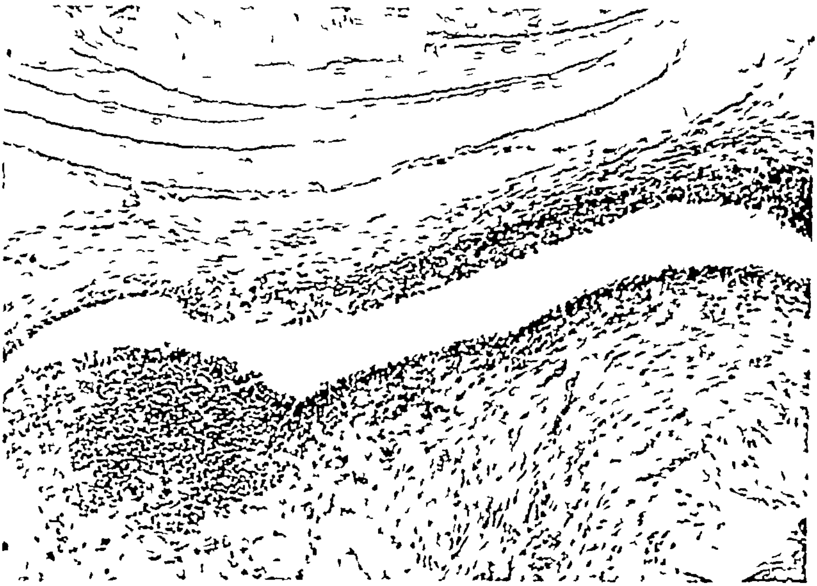


Fig 11 Microscopic view of bone removed from mastoid showing new lamella being laid down in an area of osteogenesis adjacent to fibrotic granulation tissue with round cell infiltration

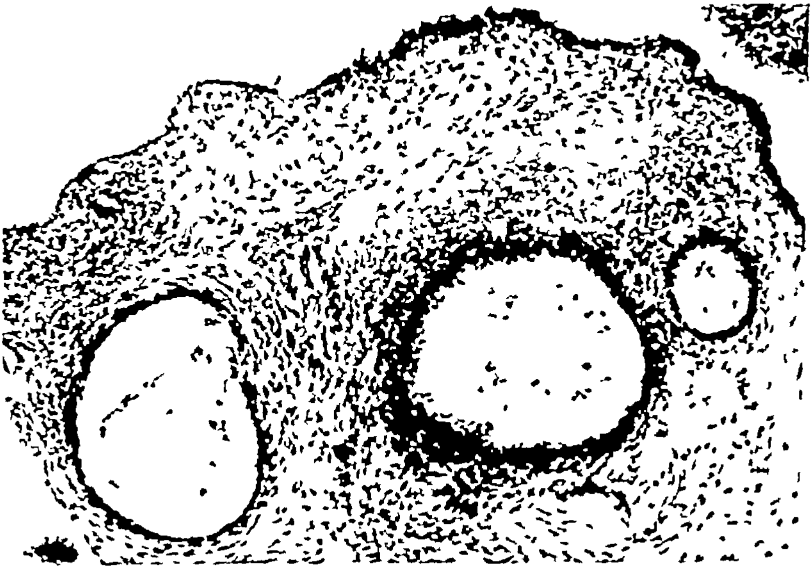


Fig 12 Microscopic view of cystic spaces in granulation tissue removed at mastoid surgery

Granulation tissue is present in the cellular remnants, in the antrum and about the ossicles Unsuspected cholesteatoma was found in two cases The ossicular chain is usually intact The bacteriology has been omitted, because it was noncontributory

*Microscopic* The chronic mastoiditis usually exhibits a

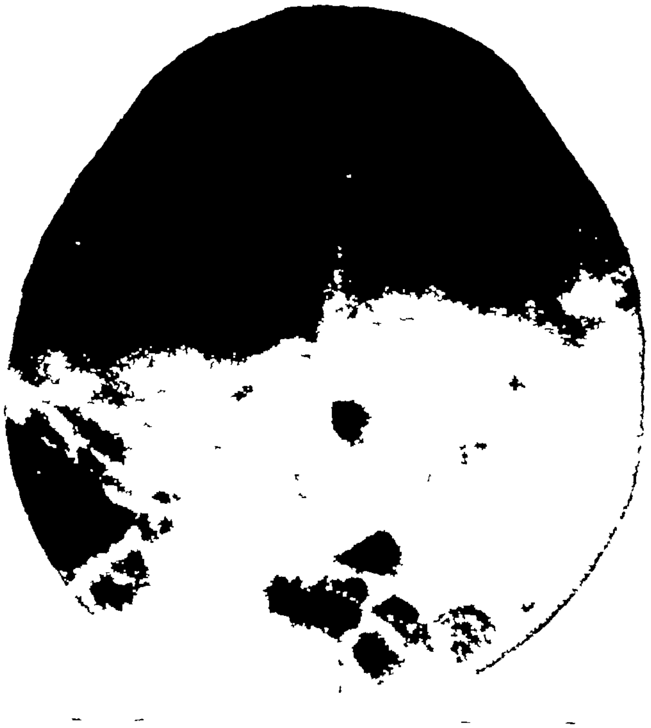
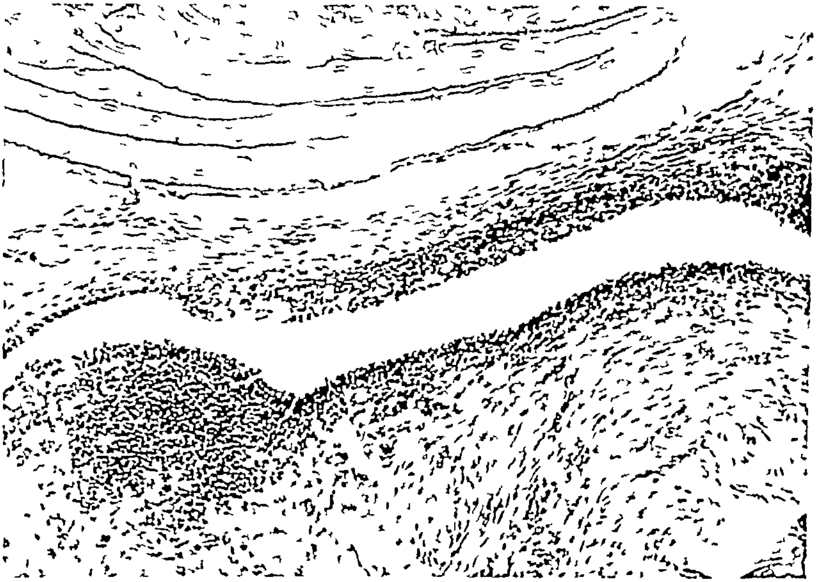


Fig 13 X-ray of extensive mastoiditis in previously pneumatized cavity with extensive sclerosis beginning

hyperplastic mucosa with extensive round cells infiltration, plasma cells and edema The fibrosis is advanced in older cases Cystic spaces occur with cholesterine crystals Necrotic spicules of bone and empty lacunae with eroded cement lines are found in the more degenerative areas There are evidences of new bone formation with parallel darkly stained cement lines and osteoblasts (see Figs 11, 12)



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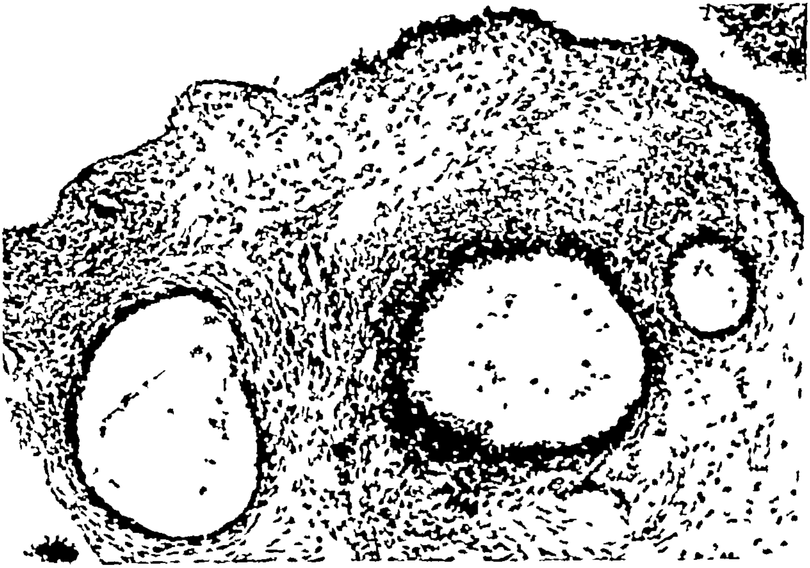

Fig 12 Microscopic view of cystic spaces in granulation tissue removed at mastoid surgery

of a previously pneumatized mastoid with small areas of necrosis, lack of aeration and extensive sclerosis as a part of the co-existing process of bone disease and osteogenetic repair This was confirmed by the pathology found at surgery It demonstrated the irreversibility of the disease, and often more extensive infection and destruction than had been expected was encountered This was particularly demonstrated in the attic along the dural plate and in the perilabyrinthine

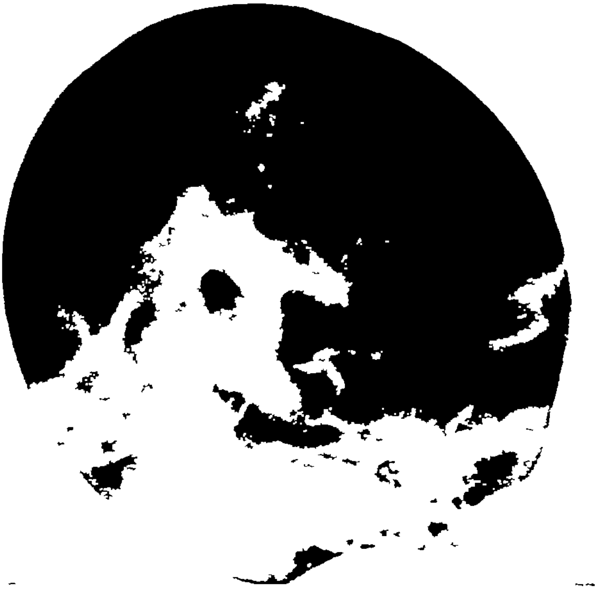

Fig 15 X-ray of a chronic mastoiditis showing extensive destruction and confluence of cells in the entire posterior aspects of the mastoid.

spaces by areas of bone necrosis, also unsuspected cholesteatoma was found in two cases Complete atticomastoidectomy without taking down the posterior or superior canal wall was performed All cases so treated resulted in a complete resolution of the temporal bone suppuration Most patients enjoyed a hearing improvement, often returning to the normal level of hearing Closure of the tympanic perforation often occurs spontaneously If the perforation is large it may be undertaken with tympanoplasty In most cases it

## X-RAY

The mastoid was usually well developed on X-ray examination Sclerosis, loss of individual contours of cells and cloudiness of antral and periantral regions was observed, and larger peripheral cells, which may have been the result of confluence were common Their trabecular walls were markedly thickened Figs 13, 14 and 15 are typical X-ray views of mastoid pathology which could benefit from this type of surgery

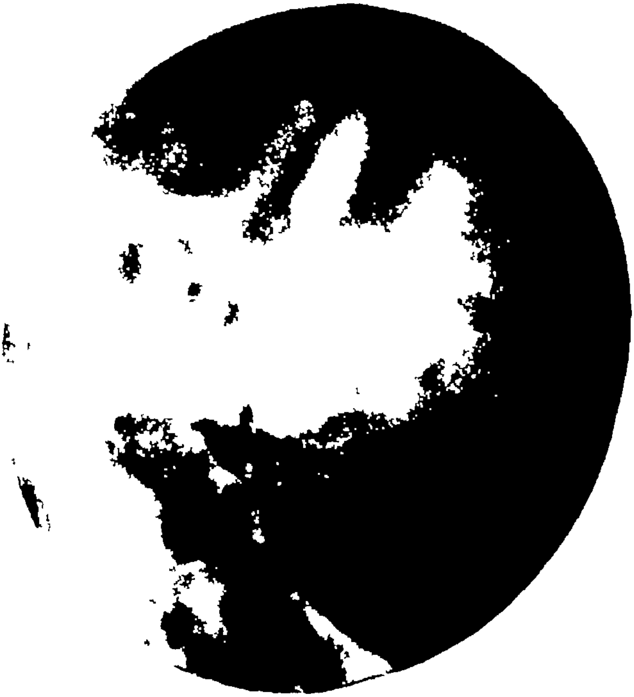

Fig 14 X-ray of a more contracted mastoiditis with a small area of destruction over the sinus

## SUMMARY AND RESULTS

Nine cases of chronic suppurative otitis media, with central perforation, have been presented which did not respond to all current methods of nonsurgical therapy In these patients the X-ray picture of the mastoid usually gives the impression

# STAPEDIO-VESTIBULAR OSTEOTOMY IN OTOSCLEROSIS

MICHEL PORTMANN, M.D.,
and
GILBERT CLAVERIE, M.D.,
Bordeaux, France

Stapes surgery has steadily improved since Rosen described his method for stapes mobilization in 1952. This operation is rational and fascinating, because it is essentially physiological. Despite this fact many otologists who have tried this surgery have been disappointed; in fact, the first reported statistics of the results showed only 40 per cent success. Several factors are responsible for the high incidence of failures obtained.

First, it is difficult to check thoroughly the extent of the pathology at the footplate of the stapes. It becomes even more difficult to perform the best surgical maneuvers suited for this particular type of footplate pathology. Manipulations often result in crural fractures rather than fractures in the articular interline itself. Occasionally the concomitant association of a complete closure of the round window by otosclerosis renders ineffective a successful stapes mobilization. In spite of these disadvantages many authors realize that the future of otosclerosis surgery lies in this type of operative approach, because it is rational and physiological.

Following "simple stapes mobilization" otologists began considering "stapes surgery," and even the concept of a "surgery of the labyrinthine window."[1] We mentioned in a previous report[1] the different procedures which we employ in the frame of this surgery according to the pathology encountered. We particularly emphasized the stapedo-vestibular osteotomy, which is the object of the present report. Its technical elements are as follows.

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has been our practice to delay closure of the drum by tympanoplasty because antibiotic dusting of the antral drain and middle ear is more efficient with an open drum membrane and also because postoperative closure can occur spontaneously, or be encouraged with trichloracetic acid cauterization. We usually delay tympanoplastic closure until after the ear has demonstrated a prolonged period of healing and has not closed spontaneously.

### CONCLUSIONS

Atticomastoidectomy may be performed for chronic suppurative otitis media with central perforation of the tympanic membrane in appropriate cases with expectation of a cessation of discharge, resolution of the disease and restoration of normal or improved hearing.

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## SEVENTH INTERNATIONAL CONGRESS OF BRONCHOESOPHAGOLOGY

The Seventh International Congress of Bronchoesophagology will be held at Kyoto (Japan) University, September 12-14, 1958, under the direction of Prof. Mituharu Goto, M.D., Otorhinolaryngological Clinic, Kyoto University Hospital, Kyoto, Japan.

A registration fee of $25.00 U.S.A. will be charged all physicians and a fee of $10.00 for wives or non-medical guests. Registered members are admitted free to banquet, receptions and sightseeing tours.

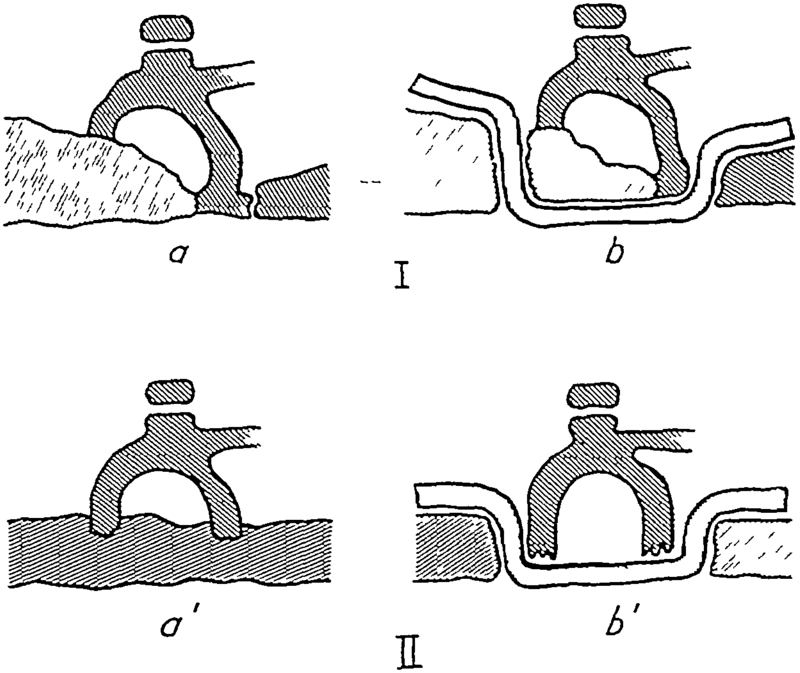

Fig 2 Principle of the Osteotomy with Interposed Graft.—I Osteotomy Type I—We can conserve the footplate a before the operation b after the operation
II Osteotomy Type II—We cannot conserve the footplate a. before the operation b after the operation

## I APPROACH

The approach must be large so as to see the whole stapes with its footplate The operation includes either the retro- and supra-auricular approach which is large,[1] or the trans-meatal approach When we employ the latter the phases are as follows

*First phase* (Incision)

An incision is made one-half centimeter from the sulcus tympanicus from one to six o'clock on the left, or eleven to six o'clock on the right posterior canal wall

*Second phase* (Elevating)

The tympanomeatal flap thus formed is elevated and displaced anteriorly

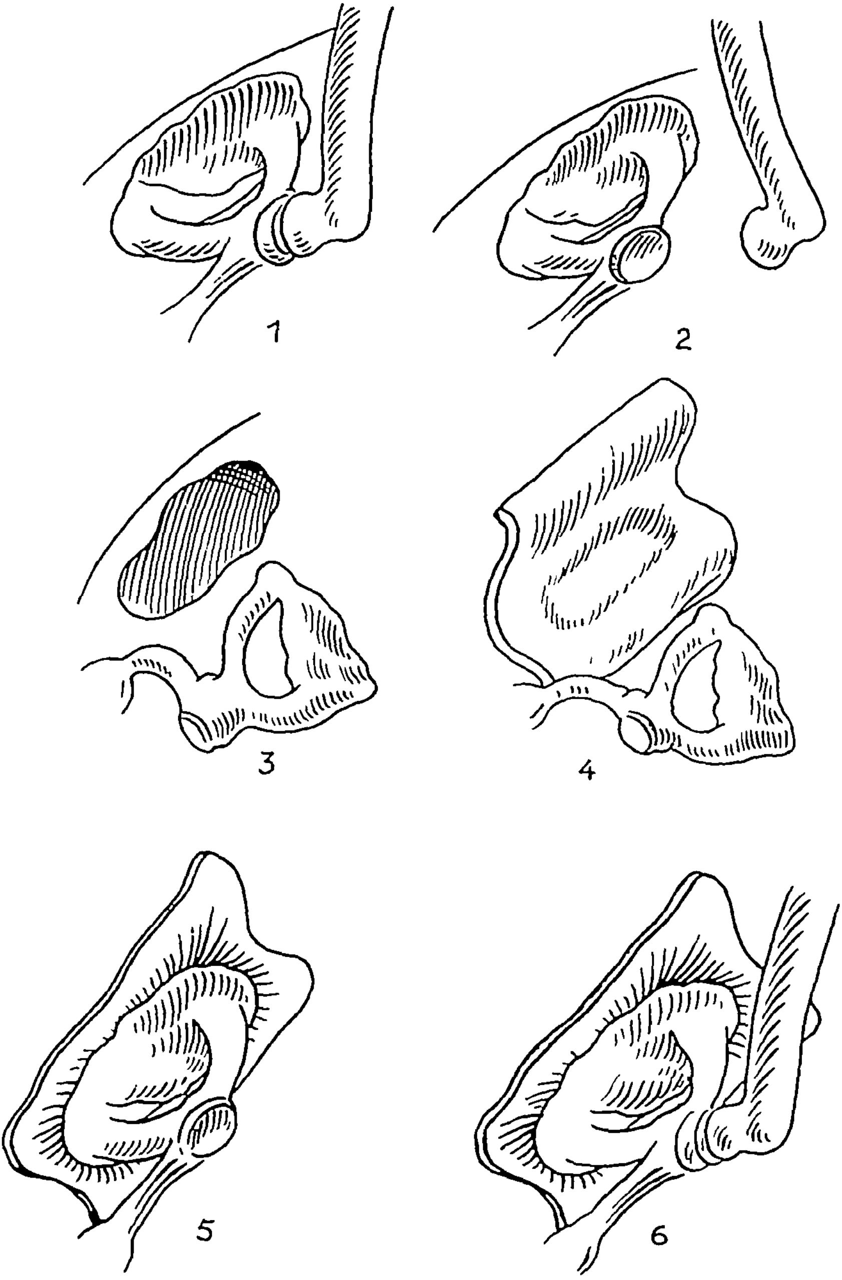

Fig 1 1—Stapes aspect before the operation 2—Disarticulation of the incus 3—Osteotomy and removal of the stapes 4—Graft on the oval window 5—The stapes is replaced in good position on the graft 6—The incus is replaced on the stapes head

Schematically the various essential aspects are

1 If it is beginning otosclerosis with a normal stapes and a visible articular interline a "simple mobilization" could be sufficient, however, it is always carried out by working on the footplate itself Direct action on the neck or head must be given up, or at any rate should be used only to finish a mobilization which has already been performed by maneuvers on the footplate

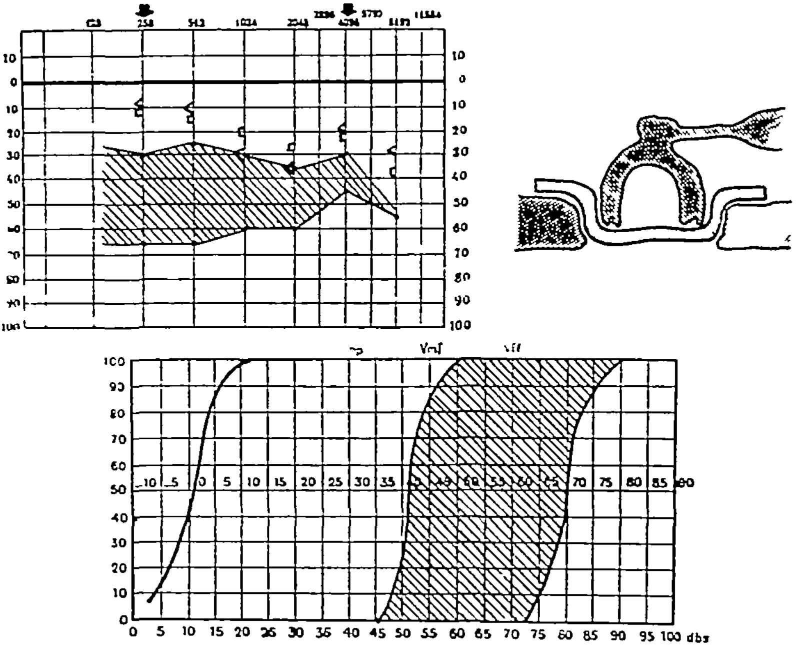

Fig 4 An Example of the Result Given by an Osteotomy—Type II Shaded part the audiometric gain [ bone conduction before the operation < bone conduction after the operation

2 If the osteome fills up a normal stapes because it presses against the crus, the osteotomy allows the removal of the part of the osteome which disturb the motion of the stapes

If the osteome has overgrown the anterior part of the articular interline, according to Fowler Jr, you can do a

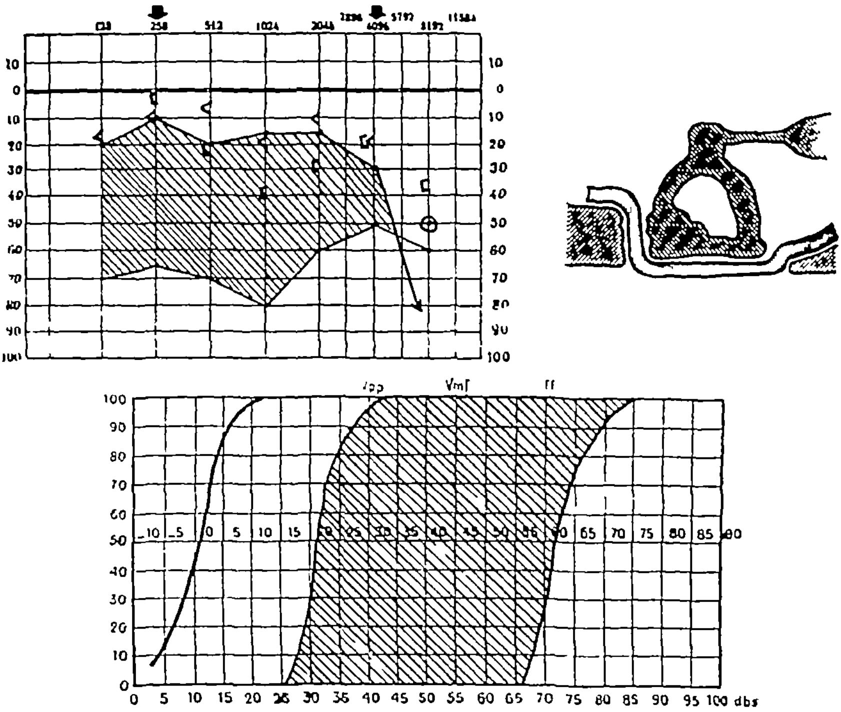

Fig 3 An Example of the Functional Result Obtained by Osteotomy—Type I. Shaded part the audiometric gain [ bone conduction before < bone conduction after the operation A bone conduction gain is also noted

*Third phase* (Corda Tympani)

The corda tympani nerve is isolated and displaced anteriorly It can be cut if it is in the way

*Fourth phase* (Bone Resection)

Bony resection of the annulus is very important, in order to provide a good view of the whole stapes We prefer to use a bur with a bent hand-piece for this phase

*Fifth phase* (Disarticulation of the Incus)

The incus is detached at the level of the stapes head and pulled to the front It is replaced after the stapes phase

## II PHASE OF STAPES SURGERY

The pathology on the periphery of the stapes is analyzed with 16 magnifications or higher

### *Technique of Osteotomy with Interposition.*[3]

An objection could be made to the simple stapedo-vestibular osteotomy, in fact, the new interline obtained by the operation divides two pathological bony surfaces which are very active It is, therefore, logical to think that after a few years both parts of the osteome will unite again We tried to improve this osteotomy by the interposition of a tissue so as to prevent re-ankylosis The graft to be applied on the oval window must be very thin After various experiments we decided on the vein graft previously proposed by Shea, Jr, that is, a small section from a vein of the back of the hand cut open along its long axis The connective tissue is thinned down This graft constitutes an excellent material to apply on an oval window

*Type I* As soon as the osteotomy is performed the stapes is removed from its frame so that the oval window is open, however, the ossicle keeps one connection with the walls of the tympanum by its muscle tendon which is not cut off It is turned over its tendon and pulled down so that it does not impede work on the oval window itself The mucosa which surrounds the window is removed The graft is then applied to the window with its adventicia toward the labyrinth and its endothelium toward the tympanum Finally the stapes is replaced into its proper place in the window, but on the graft which is used as an interposition

*Type II* In certain cases the window is completely closed by a very thick and white bone from which the crura seem to emerge It is not possible to create a footplate in such a lesion We must then cut the crura near the osteome so that the stapes consists of only the head and crura It is still attached to the stapedius tendon The oval window is then cleared of otosclerotic bone The graft is applied, endothelial side out, to the recreated oval window The stapes is then replaced with the ends of the crura directly connected with the vein graft, which is used as a footplate

## III CLOSURE OF THE OPERATIVE FIELD

Bleeding must be avoided After suction the necessary section of the anterior crus and the anterior part of the footplate to isolate the lesion One can also make an osteotomy

3 In many other cases the osteome is more extensive and occludes the articular line We can then perform a stapedo-vestibular osteotomy

4 Sometimes the lesion covers the entire stapes completely In this case it is again possible to try an osteotomy and a "fenestration" in the area of the oval window

We have then several methods of stapedio-vestibular osteotomy available according to the type of pathology

*Instruments*

We employ the following instruments

Thin osteotomes needles and fine hooks with a straight handle and also with a spoon-shaped handle The shape of the latter (after the Zollner idea) facilitates visibility but does not permit the rotary motion, which is possible only with a straight handle instrument

A special microdrill, already described [2]

Thin suction tubes permitting the washing with serum This liquid with a composition similar to perilymph should be used at 37° centigrade

*Technique of the Simple Osteotomy*

With the thin osteotomes (needles) small holes are made in the expected zone of the articular interline We must be careful not to crack the crura When this maneuver is impossible, due to the thickness of the bone, we must have recourse to the microdrill This permits the performing of microscopic labyrinthine trepanations like a dotted line crossing the lesion It is then possible to fracture the bone between the holes and thus obtain mobilization In some cases the pathology is very localized, generally in both the upper and anterior part, so that the osteotomy must be performed only in this area Occasionally the footplate is atrophic, transparent and contrasts with the density of the anterior part Then the action must be very gentle in order to avoid its fracture

### *Technique of Osteotomy with Interposition*[3]

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## III CLOSURE OF THE OPERATIVE FIELD

Bleeding must be avoided After suction the necessary microcoagulation is performed The incus is put back in place on the head of the stapes The corda tympani nerve is replaced and finally the tympanomeatal flap

Post-operatively the patient may present a syndrome of labyrinthine irritation, sometimes severe, with nystagmus toward the side of the operation The slightest motion of the head may provoke dizziness and nausea This reaction disappears within a few days Sometimes there is no reaction at all

## CONCLUSION

These surgical procedures are still in the experimental stage The excellent results which we have obtained with them indicate that they are an improvement in stapes surgery The percentage of success for all stapes surgery is steadily increasing despite many persistent technical difficulties and as yet unestimated surgical risks We believe that future technical progress will result in maximum results

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## AMERICAN BOARD OF OTOLARYNGOLOGY

The American Board of Otolaryngology will conduct only one examination in 1958, and this will be October 6-9, 1958, in Chicago, Illinois, at the Palmer House

For further information address Dr Dean M Lierle, Secy-Treas, University Hospital, Iowa City, Iowa

# UNILATERAL PARALYSIS OF VOCAL CORD FOLLOWING ADMINISTRATION OF TETANUS ANTITOXIN (TAT) *

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Any peripheral neuritis after administration of tetanus antitoxin (TAT) is very rare, if one considers the enormous number of persons treated with it Involvement of the recurrent laryngeal nerve is even less frequent, but nevertheless it should be known that it may occur Bearing this in mind may be helpful in establishing the correct diagnosis of unilateral vocal cord paralysis of "unknown" origin The prognosis is uniformly good and no specific treatment needed Incidentally ACTH and Cortisone have been tried without any significant acceleration of recovery

The etiology and pathology of this entity were well discussed in previous papers,[1,4,10,11,12] and the reader is referred there for details Involvement of the recurrent laryngeal nerve probably follows the same pattern as in other peripheral nerves, *i e* edema of the nerve due to impaired blood supply, which causes temporary damage to the nerve and impairs its function The damage to other peripheral nerves, especially those of brachial plexus, may be permanent, and certain authors assess the incidence as high as 20 per cent [4,12] In both of our cases, in spite of good and relatively fast functional recovery, there remained some sluggishness in movements of both vocal cords and arytenoids even six months after the onset of the paralysis One year later, however, both cases showed normal function

It is generally stated that neuritic complications after TAT appear about one week after its application [4] This was true in our second patient, who had a paralysis of the left vocal

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cord as a single complication after TAT administration The first patient, a case of severe tetanus infection, had a right brachial plexus involvement with paralysis of right vocal cord which was discovered in the fourth week of hospitalization Here, however, TAT was given both prophylactically and later on, therapeutically, in high doses, so that it was hard to decide which one of these separate doses of TAT was the cause of paralysis

## REPORT OF TWO CASES

*Case 1* P R, 18 years old white male admitted on September 2 1952, with chief complaint of stiffness of neck and pain in throat and shoulders of 16 hours duration One week prior to the admission the patient fell down cutting his right forearm on a dirty rock The wound was sutured by a local physician, a prophylactic dose of TAT was given and the patient started on penicillin twice a day Two days prior to the admission the wound became infected and several sutures were removed by the local physician The following day the patient began to feel stiffness in his neck and throat and was running temperature On admission there was stiffness of neck pain on motion of neck shoulders and upper back muscles Trismus was pronounced, making the examination of the larynx impossible There was, however, no hoarseness and no respiratory distress Laceration 6 cm long on the right lower forearm was infected and partially closed with three sutures The wound was opened, cultures and smears taken which eventually grew Clostridium tetani debridement and treatment with irrigations and soaks were carried out Patient received 200,000 units of TAT 60 000 of which were injected around the wound and 140 000 i m In spite of heavy sedation he had frequent attacks of opisthotonic spasms and required tracheotomy on the second day for laryngospasm After a severe and rather stormy course he improved after three weeks, and tracheotomy tube was removed on the twenty first postoperative day Toward the end of the fourth week of hospitalization it was discovered that he was hoarse, and indirect laryngoscopy showed a paralyzed right vocal cord At the same time he developed weakness of right shoulder, forearm and wrist He was improving quickly without any specific therapy, and three months later his voice was normal and only some sluggishness of the movements of the right cord and right arytenoid still persisted Last check on April 29, 1954, showed a perfectly normal function of both cords

*Case 2* F L 43 years old, white male was seen at E N T Clinic on June 9 1953 with a chief complaint of hoarseness of seven weeks' duration Indirect laryngoscopy revealed a paralysis of left vocal cord with minimal movements of left arytenoid His history was essentially negative except that he was given 'a tetanus shot" by his local physician for puncture wound of his foot One week following the injection he suddenly became dyspneic and hoarse Dyspnea disappeared soon, but hoarseness persisted Patient was referred to Speech Clinic for speech therapy and improved very much in one month When seen at E N T Clinic one year later his left vocal cord showed normal function

## SUMMARY AND CONCLUSIONS

Two cases of paralysis of the recurrent laryngeal nerve are reported where the cause apparently was the reaction to TAT The first case developed unilateral paralysis of the vocal cord after therapeutical dose of 200,000 units of TAT after having received a prophylactic dose one week before therapy was started In this case there was an associated involvement of right brachial plexus The second case developed unilateral paralysis after prophylactic dose of TAT, and this was the only complication present

Both cases improved functionally *ad integrum* within six months without any specific therapy The second case received speech therapy, which we believe was helpful to overcome faster the acute period of voice impairment and helped him in social readjustment

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# DIFFERENCE LIMEN OF INTENSITY IN HEARING IMPAIRMENT DUE TO CRANIOCEREBRAL INJURY *

ARMO L HORMIA,

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Auditory damage in connection with craniocerebral injury is due to labyrinth concussion, which damages the organ of Corti This has been confirmed by both experimental studies (Schuknecht[20]) and by clinical observations (Drooker,[6] Grove[9]) According to the severity of the blow, the end-organ damage consists of loss of the external hair cells, loss of the external and internal hair cells, or complete disappearance of the organ of Corti (Schuknecht[20])

In Ménière's disease, recruitment is a constant finding This is also the case in end-organ deafness caused by acoustic trauma In retrolabyrinthine hearing disorders, on the other hand, recruitment does not exist (Day,[4] Dix,[5] Eby and Williams,[7] Reger and Kos[18]) Even though the difference limen and recruitment phenomena are not exactly identical, they are, however, based on related physiological backgrounds (Fowler,[8] Hirsh,[10] Lund-Iversen,[14] Tonndorf[21]), therefore, in cases with recruitment, a reduced difference limen for intensity has been observed and vice versa (Békésy,[1] Lundborg,[13] Luscher,[16] Jerger[12])

As the hearing loss following head injury, is due to end-organ damage, one might suppose that the recruitment phenomenon and a reduced difference limen should be characteristic for it, however, clinical observations show that patients with concussion of the labyrinth after severe head trauma do not respond uniformly Both cases with decreased difference limen and recruitment, as well as cases with normal difference limen and without recruitment have been seen (Luscher,[16] Saltzman[19])

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*From the Brain Injury Hospital Helsinki Eero Hillbom M D Chief

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## MATERIAL

The difference limen in hearing impairment due to craniocerebral trauma was investigated by means of Bekesy[1] audiograms in a series of 43 war veterans In this series were included all cases with a hearing loss of at least 30 db in one or more frequency ranges The age of the patients varied from 30 to 50 years, being 37 years on an average The investigation was carried out on an average of 12 years after injury In every case a detailed neurologic investigation was undertaken, and in a detailed psychologic investigation, special attention was given to signs of impaired perception and attention capacities In each case, the subjective troubles caused by the hearing impairment were also noted In the symptomatology, the symptoms of cerebral injury dominated, the hearing impairment being of secondary importance In 30 cases the primary injury had been a local cranial trauma due to high-speed missiles, generally shrapnel and bullets In the other 13 cases the primary injury had been a craniocerebral concussion

In analogy with Lundborg,[13] the Bekésy[1] audiograms were grouped in four types according to the amplitude of the difference limen Type IV represents a strongly reduced difference limen, Type III a partially reduced one, Type II, a tendency to a reduced difference limen, and Type I, a normal difference limen In addition to this, patients with a difference limen higher than 20 db at some frequency ranges formed an extra group of a high difference limen (Luscher[16])

## RESULTS

In one single case the Bekésy[1] audiogram represented Type IV This was a case of temporal injury The hearing was impaired, and the reduced difference limen was present in the ear opposite the site of injury This finding is not at all in accordance with the pattern of hearing impairment seen in temporal injuries (Hormia[11]) Indeed, in the light of other clinical findings, this case could be diagnosed as morbus Ménière, independent of the trauma

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In four cases the Békésy[1] audiograms represented the Type III, and all belonged to the group of local injuries

In eight cases the Békésy[1] audiograms represented Type II From these, five were local injuries and three concussions

In nine cases, the Békésy[1] audiograms represented Type I, with a normal difference limen Of these, three were local (right temporal) injuries, and six were concussions

In 23 cases the difference limen was higher than normal From these, 19 were local injuries (with a total of seven parietal) and four were concussions In two cases the difference limen decreased somewhat in higher frequency ranges (These cases are, therefore, included also in the group of Type II) The highest average difference limens seen in this series were 30-35 db

TABLE I

The correlations between the amplitude of difference limen in Békésy audiogram and the hemisphere of the craniocerebral injury the effectiveness of perception and attention capacities, and the subjective inconvenience of the hearing impairment

| | Hemisphere of the Head Injury | | Perception and Attention | | Hearing Impairment Subjectively | |
|---|---|---|---|---|---|---|
| | left | right | impaired | others | not disturb | disturb |
| Cases with High Difference Limen | 15 | 8 | 10 | 13 | 17 | 6 |
| Other Cases | 8 | 12 | 5 | 15 | 9 | 11 |

Checking the factors which could be significant of a high difference limen, it was seen that in these cases the following factors were more common than in the other cases (see Table I)

The primary injury was located on the side of left hemisphere

As a consequence of the brain injury, the perception and attention capacities were greatly deteriorated

The hearing impairment was subjectively not disturbing for the patient

Regarding no one of these factors could the results be shown to be statistically significant because of the small number of cases. The significance of these three factors may be seen more clearly by examining their total effect. From the 23 cases with a high difference limen eight had less than two of the three factors mentioned above, in 15 cases two or three of the factors were present. In the series of the other 20 cases the numbers were 15 and five. This shows a clear difference between the group of cases with a high difference limen and the other group (Statistically significant, $\frac{X}{\sigma}=2.62$).

## DISCUSSION

In the light of the material presented above, it is obvious that a reduced difference limen is not characteristic for the hearing impairment in connection with craniocerebral injuries, yet the mechanism of the hearing impairment is one of labyrinth concussion and it thus is a question of end-organ deafness. This result does not agree with the prevailing opinion that a reduced difference limen and recruitment are typical of labyrinth deafness.

Some investigators have explained the recruitment phenomenon as due to reaction of the more intact inner hair cells in cases with damaged outer hair cells (Lurie,[15] Meyer zum Gottesberg[17]). The inner hair cells lie directly against the bone, thus, it is reasonable to assume that in cases with severe head injury the concussion effect which reaches the labyrinth through the bones of the skull also damages the inner hair cells. There can even be a secondary degeneration of the peripheral cochlear neuron (Schuknecht[20]). Compared with the mechanism of acoustic trauma (Bernabei[2]) and the increased endolymphatic pressure mechanism of the hearing impairment in Menière's disease (Cawthorne and Hewlett[3]), it seems possible that in cases of blows to the head the inner hair cells receive relatively more damage, even though these are not so easily injured as the more sensitive outer hair cells.

The explanation of the absence of reduced difference limen in cases with deafness due to head trauma may be found in a more uniform damage of the organ of Corti with its nerve supply

A high difference limen was seen in one-half of the cases Luscher[16] has expressed the significance of psychic factors for the occurrence of high difference limen This observation was confirmed in the material presented above High difference limen was seen especially in cases where the cerebral injury was on the side of the dominating hemisphere and had caused a deterioration of the perception and attention capacities It was also seen that the subjective inconveniences of the hearing impairment for these patients were of less degree than for the others This can be understood as a sign of a deterioration, especially of those areas of perception and attention functions which are closely connected with auditive sensations (Hormia[11]) These findings show that the psychic factors causing high difference limen can be due to organic brain damage

## SUMMARY

The difference limen in hearing impairment caused by craniocerebral injury was studied with the Bekesy audiograms in a series of 43 war veterans In only four cases could a partly reduced difference limen be seen As a possible explanation for the absence of reduced difference limen, the mechanism of the hearing impairment in connection with head blows was considered It is a question of end-organ deafness due to concussion of the labyrinth This concussion wave reaches the labyrinth through the bones, therefore, the inner hair cells are more prone to the damage and a more uniform damage of the organ of Corti results than in those types of end-organ deafness characterized by a reduced difference limen and presence of recruitment

A high difference limen was seen in one-half of the cases In these cases signs of deteriorated (auditive) perception and attention capacities were noted The result thus confirms the significance of psychic factors upon the incidence of a high difference limen

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# BASIC TECHNIQUES IN MYRINGOPLASTY AND TYMPANOPLASTY *

FRED R GUILFORD, M D ,
and
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Houston, Tex

The work of Wullstein[1] and Zollner[2] in the practical application of the technique of tympanoplasty has stimulated otologists throughout the world to become interested in this phase of rehabilitative surgery Berthold in 1878, first closed a perforated ear drum successfully and reported several successful results Eli,[4] Tageman[5] and Roosa,[6] in America, tried the operation with questionable results There was a definite cessation in the practice of tympanoplasty from 1900, until the reports of Wullstein and Zollner again focused attention on the procedure Since then thorough studies and results were reported, it is a matter of history that the technique has been adopted enthusiastically, and modified to some extent by otologic surgeons everywhere[7-9]

We consider[10] tympanic skin grafting to be the basic technique, and the five types of tympanoplasty to be modifications of this technique These modifications depend upon the pathology found in the sound conduction mechanism, the ossicular chain, oval window and round window, as well as upon the pathology in the mastoid cavity In all types, control of suppuration in the middle ear and mastoid, as well as main-

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*Read at the meeting of the Southern Section American Laryngological Rhinological and Otological Society Inc Memphis Tenn Jan 25 1958

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tenance of an air space connecting the two mobile functioning windows to an adequately functioning Eustachian tube, is necessary. The middle ear must be lined with mucous membrane, and the cochlear reserve should be adequate for complete success of the procedure.

### PREOPERATIVE PROCEDURES

#### *I.—Control of Suppuration*

Culture and sensitivity tests are obtained, and the patient is started on specific local and systemic antibiotics when available. Burrow's solution, gentian violet or 25 per cent argyrol solutions are used locally when the tests reveal the organism insensitive to specific antibiotics. To obtain better contact between drug and organism the secretions in the middle ear are aspirated at intervals of 48 to 72 hours, and the drug administered through a cannula directly into the involved area of the middle ear. This is done in addition to local administration of the drug several times daily by the patient. If a focus in the mastoid fails to resolve, a thorough simple mastoidectomy may be done. Except when cholesteatoma is present, these methods usually produce a dry ear. If radical mastoid surgery should be necessary, it should be as conservative as possible, especially with regard to saving the annulus, mucous membrane of the middle ear and Eustachian tube function. There is little to be gained from sacrificing these structures, and they are vital in surgical reconstruction of the middle ear and sound conduction mechanism by tympanoplastic techniques.

In order to create a patent Eustachian tube and prevent recurrent infection, an adenoidectomy and sinus, or allergic treatment, may be necessary.

#### *II.—Test the Eustachian Tube Function*

Careful examination of the ear may rule out middle ear effusion and retraction pockets, and determine whether a middle ear air space is present. Politzerization, Valsalva maneuvers and catheterization and inflation of the Eustachian tube will be helpful. These procedures give valuable information, but at present we do not have an absolute test of Eustachian tube function

*III—Search for Presence of Cholesteatoma*

*A meticulous examination is made for marginal* perforations, squamous epithelium in the middle ear, or cholesteatomatous debris in the perforation Magnification with the Zeiss operating microscope will be helpful in this study Mastoid X-rays may be useful If in doubt, exploration of the mastoid, epitympanic area and middle ear is done at time of surgery before skin grafting procedures are attempted

*IV—Testing of Hearing Function*

*1* Air conduction, bone conduction, speech reception threshold and discrimination tests are done routinely

*2* Patch test—when possible a paper patch is applied to the tympanic perforation to close the opening temporarily, and an air conduction test is made with the patch in place When the patch can be applied successfully and a complete seal occurs in all areas around the periphery of the perforation, valuable information concerning the integrity and function of the ossicular chain may be obtained If closing the perforation with a paper patch increases hearing appreciably, the ossicular chain is presumably intact

*3* Acoustic Probe—In those cases when it is not possible to apply a patch successfully because of the size of the defect in the drum, the acoustic probe is used to determine the efficiency of the ossicular chain In the presence of cholesteatoma the acoustic probe test results may not be reliable, because it is possible for the cholesteatomatous mass to act as a conducting mechanism between the parts of a disrupted chain The results may indicate that the chain is intact and functioning, but an obvious defect in the chain may be apparent following removal of the cholesteatoma, especially in the area of the incus

## TECHNIQUE OF MYRINGOPLASTY

*Special Problems Associated with Tympanic Skin Grafting* The successful take of the graft while bridging an air-containing cavity (the middle ear), is an important problem in this type of skin grafting The bed for this graft lies peripherally, formed by denuding the tympanic remnant, the annulus, and often the adjacent canal wall, of squamous epithelium These skin grafts differ from the usual skin graft in that their central portion, which overlies the defect, is not in direct contact with any blood supply

Most authorities agree that the permanent blood supply of a graft occurs when endothelial vascular buds grow from the bed blood vessels out into the graft and make continuity with the graft blood vessels between the fourth to tenth postoperative day Paget[11] and Conway[12] feel that most skin grafts survive the first few days on a plasmic circulation diffusing extra-cellularly from the bed blood vessels up into the graft We have previously reported our belief that this type of circulation could nourish only that portion of the graft which lies directly adjacent to the bed, and we believe that some primitive type of intravascular circulation nourishes the central portion of the graft soon after its application to the bed We believe that an intravascular circulation begins within 24 hours through the matching of the many severed ends of the capillaries in the graft with the numerous capillary endings in the denuded vascular bed Thus an early intravascular circulation occurs through the parallel subepithelial vascular network into all portions of the graft A tympanic skin graft must be cut thick enough to include the network of blood vessels running parallel to the skin surface

In general, there are two such networks a superficial one running just below the dermal papillae, and a deep one lying in the middle of the dermis These vascular networks have rich anastomoses A thin split thickness graft may contain none of this parallel blood supply, and the central portion of the graft would probably slough The full thickness graft and the three-fourths thickness split graft contain both the superficial and deep vascular networks and are better suited for tympanic skin grafting We prefer the three-fourths thickness skin graft, as it is not necessary to clean the fat from the under surface of the graft, and possible trauma to the graft's blood vessels is avoided

Only gentle pressure should be used in packing the graft in place Pressure of greater than 10 cm of water may collapse the capillaries in the graft and cause a slough of the central portion of the graft

We have previously reported other factors which we believe are important in successful tympanic skin grafting

*I Absence of Infection* To guard against latent infection, surgery should be postponed until the ear has been perfectly dry for at least 30 days We recommend pre- and postoperative antibiotics, sterile surgical preparation, sterile operating room technique and sterile postoperative care in office dressings A two-stage operation may be necessary, with the first eradicating the infection, and the second repairing the middle ear defect after the infection is completely controlled

*II Good Exposure of the Entire Tympanic Remnant and Annulus* This is a vital factor in the success of the procedure done through the transmeatal route and can be an important factor in the conventional endaural approach as well Occasionally the transmeatal procedure can be done through the intact ear canal, but a modified endaural and anterior U-shaped incision is usually required, and enlargement of the bony canal may be necessary

The bed must be completely denuded of every vestige of squamous epithelium, and the graft must be placed in close apposition to the bed with an adequate overlap Binocular magnified vision of all surfaces is required, and the anterior sulcus formed by the tympanic remnant and the anterior canal wall at the annulus is the most difficult to visualize properly In the transmeatal approach, it should be remembered that the visibility is never so good as it appears to be at the beginning of the operation

*III Atraumatic Preparation of the Vascular Bed and Handling of the Skin Graft* The graft and the bed should be prepared with only the sharpest instruments They should not be allowed to dry, and the graft should not be washed in normal saline or other so-called physiologic solutions, which may be injurious to the graft Crushing of the graft with scissors or forceps should be avoided

*IV Regrafting* If the primary graft fails because of slough, it is well to regraft as soon as the failure is discovered The first graft invariably stimulates the vascularity of the bed, and the second graft is more likely to succeed than the first if repeated within the first three or four months

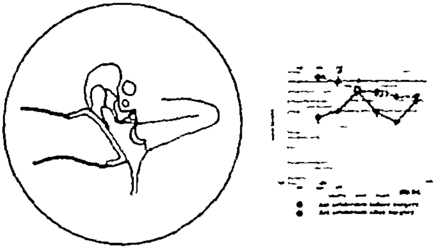
## TECHNIQUE OF MYRINGOPLASTY

*Type I—Tympanoplasty* Anesthesia is obtained by injection of 2 per cent xylocaine with 1 50,000 adrenalin in the postauricular sulcus and mastoid area At the osteocartilaginous junction in the canal, and along the roof of the canal, 1 5000 adrenalin is used in the xylocaine for hemostasis In some individuals supplementary general anesthesia in the form of intravenous pentothal is advisable (see Fig 1)

MODIFICATIONS OF TYMPANIC SKIN GRAFTING

TYPE I

Pathology Simple perforated tympanic membrane with intact ossicular chain
Rx Skin graft closure of the perforation will result in essentially normal hearing



Mrs AC—Age 29 Large 6 x 6 mm dry central perforation present for 10 years Patch and acoustic probe revealed an intact ossicular chain Mastoid x rays negative
Rx: Type 1 Tympanoplasty

Fig 1

A modified endaural incision is made (see Fig 2) and the first incision is carried along the roof of the canal to a point 2 mm from the drum A second incision is then made across the posterior wall of the canal parallel, and 2 to 3 mm lateral to the annulus It extends as far as the junction of the floor of the canal with the posterior wall A third incision is then

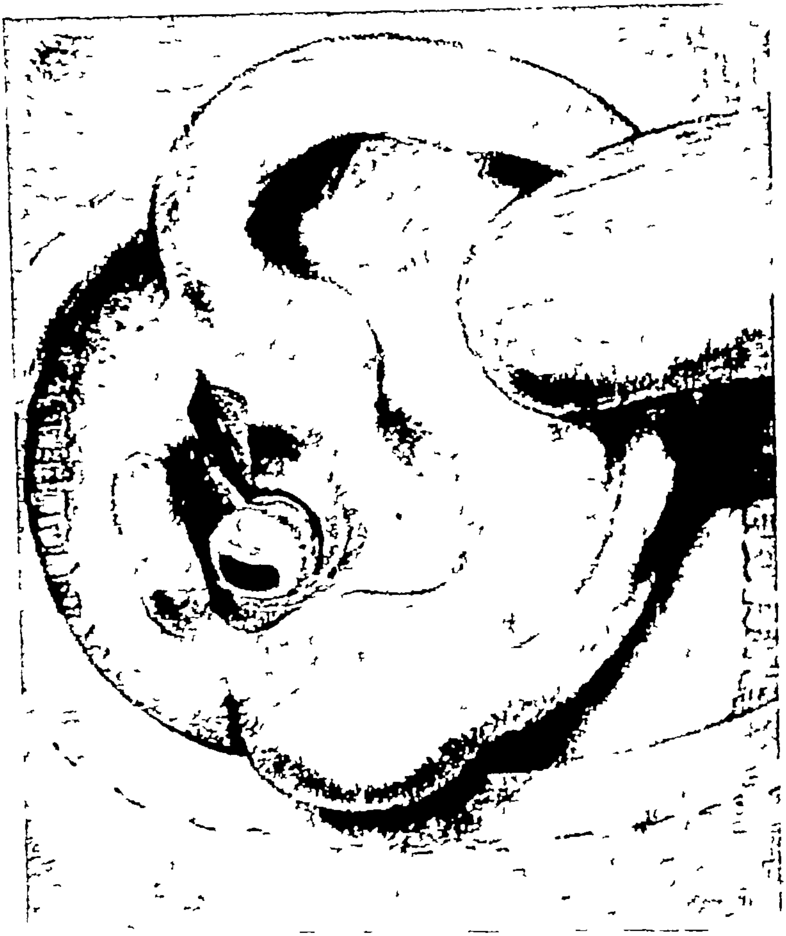


Fig 2

made from the inferior end of the second incision laterally to the osteo-cartilaginous junction The skin flap outlined on the posterior canal wall by these incisions is then elevated laterally After partial elevation of the periosteum over the mastoid process, the posterior canal flap is tucked between the overlying soft tissue and the mastoid process, to be replaced in the canal at the end of the operation A self-retaining retractor is inserted, leaving both hands free for instrumentation A U-shaped flap is now cut from the skin of the anterior canal wall (see Figs 3, 4) The lower portion of the U extends across the canal parallel to, and approximately 3 mm lateral to the annulus The vertical portion of the U falls into the junction of the roof of the canal with the anterior wall and the junction of the floor with the anterior wall respectively The vertical incisions extend to the osteo-cartilaginous junction on the anterior wall The anterior flap is then elevated and rolled up onto the skin of the anterior cartilaginous level, to be replaced at the end of the operation The overhanging bone of the anterior canal wall is thinned with a sharp mastoid curette until the anterior sulcus can be well visualized

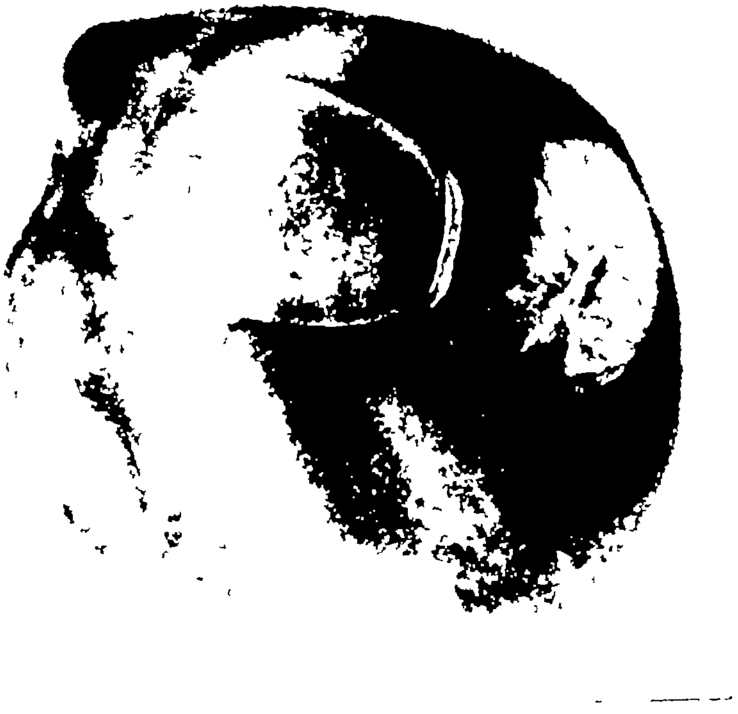


Fig 3

The graft bed is prepared by removing the outer layer of squamous epithelium from the rim of the drum and adjacent canal wall with specially made tympanic membrane curettes Occasionally a sharp knife is used to trim the cuff from the inside of the perforation which is formed by the junction of the squamous epithelium with the mucous membrane from the undersurface of the drum After denuding the fibrous layer, the perforation is measured with a fenestrometer An appropriately sized three-fourths split thickness graft is then cut with a "Weck" razor blade from the non-hair bearing skin over the mastoid The graft is placed raw surface up on a tongue blade and cut to measure with a scalpel, so that it overlaps the perforation 2 to 4 mm in all directions save

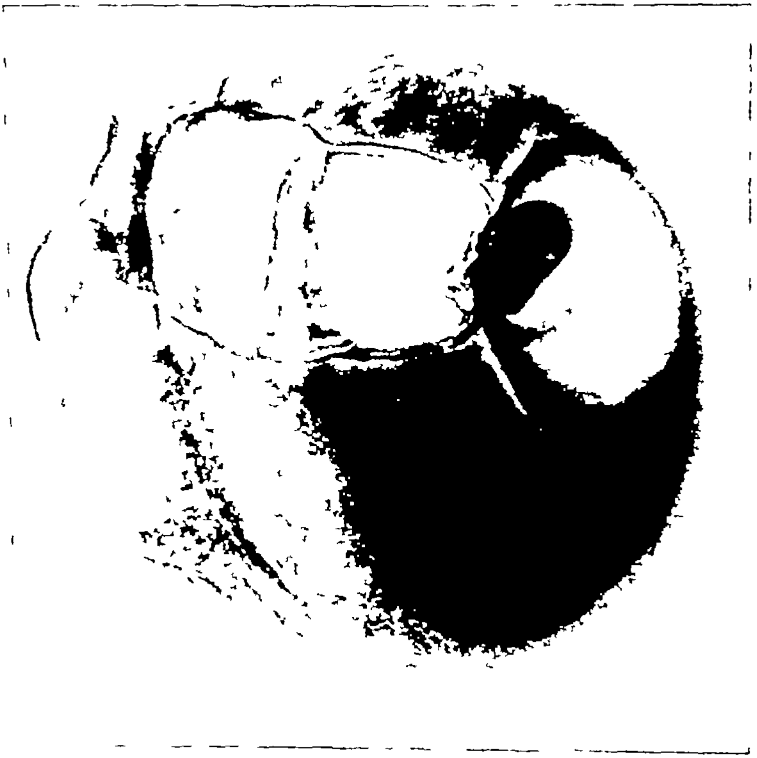
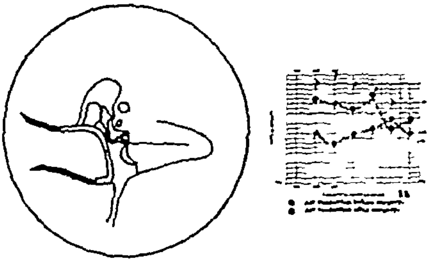


Fig 4

posteriorly, where it overlaps 4 to 6 mm The graft is placed in position on the tympanic remnant, and all edges are everted with sharp picks It is then pushed into contact with the drum and anterior sulcus with a wire ring curette The graft is then covered with small strips of cigarette paper, and one-sixteenth-inch cotton balls are gently placed against the annulus and over the central portion of the graft The anterior and posterior skin flaps are now rolled back into place, covered with cigarette paper strips, and the remainder

*TYPE IIA*

**Pathology** Perforated tympanic membrane with erosion of malleus
**Rx** The graft is placed so that it contacts the incus



Mr RB Age 16 Draining ear since childhood Examination revealed a 5 x 7 central perforation with erosion of the handle of the malleus
Rx. Infection cleared with local specific antibiotics Tympanic skin graft used to close perforation and placed in contact with the incus

Fig 6

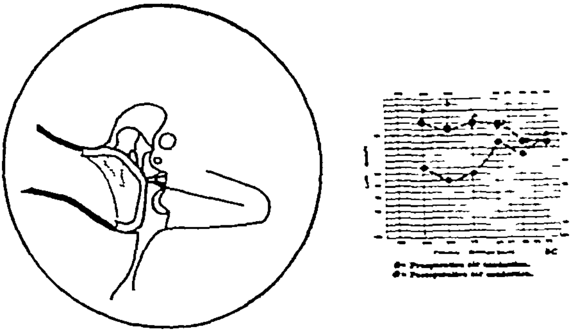
of the canal filled with antibiotic ointment impregnated cotton balls The incision along the roof is protected by a strip of surgical rayon, and the small external incision is closed with silk The donor site is covered with antibiotic ointment impregnated rayon and a mastoid dressing is applied

The patient is maintained on an appropriate antibiotic for 24 hours preoperatively, and seven days postoperatively The packs are removed on the seventh day, and the cigarette papers wiped out on the 14th day The mastoid dressing is removed after 48 hours and a small dressing applied over the rayon on the donor site, which is usually healed in 10 days

## MODIFICATIONS OF TYMPANIC SKIN GRAFTING

The Type I technique has been described We have divided the Wullstein Type II into A and B classifications (see Fig 5)

*Type II-A* Pathology—a perforated tympanic membrane with erosion of the long process of the malleus and an otherwise intact ossicular chain



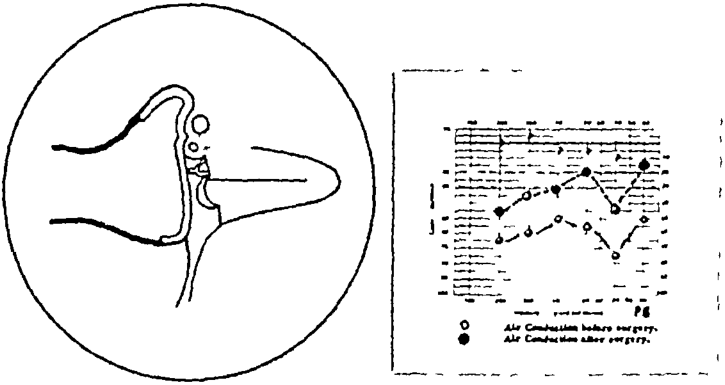
Mr BC—Age 25 Intermittent drainage from large central perforation and poor hearing all his life Patch test failed to raise air conduction, and demonstrated non-functioning ossicular chain.
Rx: Erosion of long process of incus was found in surgery, and a Type II Tympanoplasty was done

Fig 6

Technique—the graft is placed so as to contact the long process of the incus, thereby transmitting its vibrations directly to the incudostapedial joint

*Type II-B* (See Fig 6) Pathology—necrosis of the long process of the incus is present with loss of the true incudostapedial joint Fibrous adhesions across the defect between the shortened incus and stapes head do not act as a satisfactory incudostapedial joint in the transmission of sound impulses The accepted procedure in this situation has been to remove the ossicles in conjunction with a radical mastoidectomy and do a Wullstein Type III tympanoplasty In the absence of cholesteatoma we have found that this type of pathology can often be handled by modification of Wullstein's Type II tympanoplasty This technique has the following advantages

*1* It can often be done directly through the external auditory canal as in myringoplasty or Type I tympanoplasty If the status of the mastoid is unsure, exploration of the mastoid, including the epitympanum may be done, leaving the bony external auditory canal intact If the epitympanum is free of disease, it is often unnecessary to remove the incus



**Miss PB** Classical Radical Mastoidectomy cavity with a 55 db loss Stapes mobile Rx Tympanic graft used to bridge over middle ear and placed in contact with the stapes 27 db gain

Fig 7

*2* It insures an adequate air space in the stapes area of the middle ear, allowing free mobility of the new tympanic membrane and stapes

*3* Improvement of hearing may be greater than the average Type III tympanoplasty result

*4* It may avoid the inherent disadvantages of a radical mastoid cavity, however, this technique may be applied when a modified radical mastoidectomy is necessary, if a small portion of the bridge is left intact

Technique—the denuded tympanic remnant is raised from the annular sulcus posteriorly, and the incudostapedial joint area is exposed by wide removal of bone in the annular area At this time the round window area may be inspected and mobility of the stapes determined

When the graft is applied the denuded remnant of the drum and graft are depressed and packed lightly in place so as to contact the shortened long process of the incus, as well as the head of the stapes, thus the graft bridges from the annulus anteriorly to the malleus, to the incus and stapes, and back onto the posterior wall of the canal

*Type III* Pathology—Destruction of the ossicular chain is present, usually due to erosion by cholesteatoma The stapes is intact and is mobile or may be mobilized There is loss of the posterior and superior canal wall, because a radical mastoidectomy is necessary or has been done previously The annulus has been preserved and the Eustachian tube is functioning

Technique—all pathological processes are removed from the middle ear and mastoid The round and oval windows, including stapes mobility, are investigated A tympanic skin graft is applied so that it bridges from the tympanic remnant or annulus to the floor of the attic and facial ridge The graft is packed gently into contact with the head of the stapes in order that vibrations are transmitted directly to the stapes, affording a columella effect, similar to the middle ear conductive mechanism in the bird's ear

*Type IV* Pathology—Destructive processes similar to Type III except that the crura of the stapes are missing, the footplate is mobile, or a mobile oval window membrane is present

Technique—round window protection is achieved by bridging the skin graft from the annulus to the promontory, leaving the oval window exposed to direct vibration of sound

*Type V* Pathology—In addition to the pathological changes found in Types III and IV, the oval window is nonfunctional because of irreversible fixation of the stapes, or fibrosis

Technique—after fenestration of the lateral semicircular canal, the tympanic graft is applied to bridge across the middle ear space onto the floor of the attic, covering the fenestra in the lateral semicircular canal

## SUMMARY

*1* The general principles and basic techniques of tympanic skin grafting have been described

*2* The modifications of this basic technique into the five types of tympanoplasty have been discussed

*3* Preliminary preoperative procedures, including selection of patients for tympanoplasty, have been described

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## ANNUAL OTOLARYNGOLOGIC ASSEMBLY UNIVERSITY OF ILLINOIS

The University of Illinois College of Medicine Department of Otolaryngology announces its Annual Otolaryngologic Assembly from September 29 through October 5, 1958 The Assembly will consist of an intensive series of lectures and panels concerning advancements in otolaryngology, and evening sessions devoted to surgical anatomy of the head and neck and histopathology of the ear, nose and throat Interested physicians should write direct to the Department of Otolaryngology, 1853 West Polk Street, Chicago 12, Ill

# PRELIMINARY REPORT ON THE PATHOGENESIS OF DERMATOSES OF THE EXTERNAL AUDITORY CANAL

## Twenty Cases of Acute Diffuse External Otitis, Due to Deep Infections *†

EDLEY H JONES, M D,
Vicksburg, Miss,
and
TOM D NORMAN, M D, (By Invitation),
Jackson, Miss

External otitis has always been a subject of particular interest to otologists, and more recently, to dermatologists During recent years many excellent investigative studies have been reported, yet only a casual survey quickly reveals that more are indicated and needed

As previous investigators have pointed out, the term "external otitis" embraces a variety of diseases that have little in common other than that they occur in the external ear Since the external ear, auricle and canal, is entirely covered by skin, these diseases must basically be designated dermatoses It is natural that otologists are primarily interested in the acute infections of the canal, and that dermatologists are primarily interested in other dermatoses of the auricle Geographical location and climate, more specifically, temperature, humidity, and exposure, are important factors Our Southern otologists annually see many cases of acute diffuse external otitis and furnuculosis with a sharp rise in the case load shortly after the opening of the swimming season, and

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*Read at the meeting of the Southern Section of the American Laryngological Rhinological and Otological Society Inc. Memphis Tenn Jan 24 1958

†From the Division of Otolaryngology Department of Surgery and the Department of Pathology University of Mississippi Medical Center Jackson Miss

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this experience is reflected in their studies and reports, our Northern colleagues in drier, cooler climates see fewer of these cases, and are more concerned with the other dermatoses

Reviews and discussions of the subject are hampered by the lack of a simple classification that is definite, clearly understood and generally accepted Senturia[3] published a detailed classification in his book, "Diseases of the External Ear," yet his introduction of it indicated he was not entirely satisfied with it, and it could hardly be called simple

For the purpose of this presentation we will employ the following etiological classification

Acute Diffuse External Otitis

I Dermatoses due to infection

A Superficial—*1* Bacterial, *2* Viral, *3* Fungal

B Deep—*1* Bacterial, *2* Viral, *3* Fungal

II Other dermatoses

Our presentation will be confined to those cases due to deep bacterial infections We consider furunculosis a progressive development and accompaniment of acute diffuse external otitis, due to furuncle-forming bacteria These cases are the result of Gram-positive bacterial infections, Gram-negative infections are usually superficial

Our interest in this phase of this subject was aroused by Sophian and Senturia's[4] detailed report of five biopsies of acute diffuse external otitis They commented on finding dilatation of the capillary and arteriolar vessels, endothelial swelling, hyperplasia and sometimes thrombosis and necrosis, noting that these vascular reactions are usually associated with toxic or allergic reactions rather than with pyogenic infections Further they noted a high eosinophilia (average 24 per cent) in the inflammatory exudate in the tissues While they pointed out that their findings did not necessarily indicate that the inflammatory process was allergic, they recognized that "certain clinical and pathological aspects—were—compatible with a state of sensitization "

One of us has studied allergy for the past 30 years and is keenly aware of the importance of allergy in otolaryngology, but could not accept such findings as typical of acute diffuse external otitis Although the usual data were presented they did not include any history or indication as to whether those patients had an allergic background, whether they had been given previous local treatment that could have caused a complicating contact dermatitis, nor did they include any bacteriologic, cytologic or hematologic studies

Our search of the literature at that time failed to reveal any other report of biopsies of cases of acute diffuse external otitis Later Shelly and Perry[2] published an interesting investigative study on the experimental production of external otitis, reporting over 70 biopsies Obviously, we cannot use them for direct comparison with our material

In 1956 we studied biopsies and white blood counts of three cases of acute diffuse external otitis, one complicated with furuncle formation (previously briefly reported[1] but included in this study) These findings were quite different from those reported by Sophian and Senturia,[4] and prompted us to continue our studies in this field

## MATERIALS AND METHODS

To date we have studied biopsies of 27 cases We do not have complete data on all of these but can fully report 20 cases, 12 of which were complicated with furunculosis One patient was seen in the University Out-Patient Clinic, but the other 19 were private cases Insofar as possible they were taken consecutively, as they presented themselves, excepting only young children, unusually apprehensive patients, and those who came in at the very end of the office hours The biopsies were taken with the patients' knowledge and permission Approximately 0 5 ml of 2 per cent xylocaine with 1 50,000 epinephrine was slowly injected 3 to 5 mm anteriorly to the chosen site, after five minutes an elliptical V-shaped section, 2 or 3 mm wide, and 4 to 6 mm long and extending down to the cartilage, was removed The specimen was fixed in 10 per cent formalin, sections 5 micron thick were made, this experience is reflected in their studies and reports, our Northern colleagues in drier, cooler climates see fewer of these cases, and are more concerned with the other dermatoses

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|  | Case Number | Race | Sex | Age | White Blood Count |  |  |  |  |  |  | Furuncle | Month | Pathological Studies (Estimates) |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | Total | Segs | Bands | Lymphs | Monos | Bas | Eos |  |  | Segs noted in tissues | Monos noted in tissues | Eos noted in tissues | Severity of Inflammation |
| 1 | 56-67 | W | M | 45 | 16 700 | 70 | 10 | 10 | 6 | 1 | 3 |  | Aug | 20 | 80 | 1 | Moderate |
| 2 | 56-68 | C | M | 15 | 18 300 | 60 | 10 | 25 | 5 | - | - |  | Aug | 50 | 50 | 1 | Moderate |
| 3 | 56-69 | W | M | 12 | 7 700 | 49 | 7 | 29 | 11 | 1 | 9 | X | Aug | 75 | 25 | 10-15 | Moderate |
| 4 | 56-184 | W | F | 28 | 8 400 | 60 | - | 32 | 2 | - | 6 |  | Sept | 40 | 60 | 10-15 | Moderate to severe |
| 5 | 56-185 | C | F | 45 | 10 100 | 58 | - | 39 | 3 | - | - | X | Nov | 75 | 25 | 0-1 | Moderate to severe |
| 6 | 57-36 | W | M | 58 | 9,800 | 61 | 2 | 23 | 4 | - | 10 |  | Nov | 50 | 50 | 2-5 | Slight to moderate |
| 7 | 57-96 | W | F | 30 | 11 800 | 69 | 8 | 21 | 1 | - | 1 | X | Jan | 60 | 40 | 0-1 | Moderate |
| 8 | 57-97 | W | F | 67 | 8,400 | 59 | - | 35 | 2 | - | 4 | X | Dec | 90 | 10 | 0-1 | Moderate |
| 9 | 57-106 | W | M | 22 | 10 200 | 66 | - | 26 | 1 | - | 7 |  | May | 50 | 50 | 0-1 | Slight |
| 10 | 57-107 | C | F | 23 | 9 600 | 61 | - | 36 | 2 | - | 1 | X | May | 75 | 25 | 1 | Severe |
| 11 | 57-109 | C | F | 26 | 10 600 | 69 | - | 27 | 1 | - | 3 | X | Apr | 75 | 25 | 1 | Slight to moderate |
| 12 | 57-111 | W | F | 40 | 10 900 | 63 | 8 | 24 | 2 | - | 3 | X | Feb | 80 | 20 | 0-2 | Moderate to severe |
| 13 | 57-129 | W | M | 19 | 11 300 | 52 | 6 | 30 | 4 | - | 8 | X | July | 75 | 25 | 0-1 | Severe |
| 14 | 57-131 | W | F | 23 | 19,400 | 56 | 12 | 29 | - | - | 3 |  | July | 30 | 70 | 0 | Slight |
| 15 | 57-132 | W | M | 25 | 14 700 | 54 | 9 | 31 | 3 | - | 3 | X | July | 50 | 50 | 0-1 | Severe |
| 16 | 57-133 | W | M | 34 | 15 500 | 68 | 11 | 12 | 5 | - | 4 |  | July | 80 | 20 | 0 | Moderate |
| 17 | 57-134 | W | M | 16 | 10,900 | 42 | 16 | 29 | 6 | - | 7 | X | July | 75 | 25 | 1-3 | Severe |
| 18 | 57-135 | C | F | 16 | 16 700 | 56 | 5 | 37 | - | - | 2 | X | July | 50 | 50 | 0-1 | Slight to moderate |
| 19 | 57-136 | W | M | 13 | 12 800 | 79 | 6 | 14 | 1 | - | - | X | July | 80 | 20 | 0 | Severe |
| 20 | 57-137 | W | F | 22 | 9,300 | 48 | 9 | 34 | 2 | 1 | 6 |  | July | 75 | 25 | 0 | Moderate |

Chart 1

some semiserially Slides of all cases were routinely stained with hematoxylin and eosin, but slides from six biopsies also were stained by Giemsa's technique and MacCallum's modification of Goodpasture's Gram's stain A total and differential white blood count was routinely made on each patient

A statistical analysis of these cases reveals their ages ran from 12 to 67, younger patients were purposely not included Only 25 per cent were in the colored race, which confirms previous observations by other otologists The incidence in sexes was identical, but it is interesting to note that the seven cases following swimming were all males, five in their 'teens, while seven of the eight who gave a history of previous involvement were females Furuncle formation was noted at the time of first examination in 12 of the 20 cases, eight of the 15 whites, and four of the colored Oddly enough, a history of trauma was obtained in only two cases, both white adults, one male and one female Almost one-half were patients in their third decade, but there was at least one in each of the second, fourth, fifth, sixth and seventh decades Patients were seen in every season and almost every month, with more than one-half in July and August

CHART 2

| | Total | Race | | Sex | | Age | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | W | C | M | F | 11 20 | 21 30 | 31 40 | 41 50 | 51 60 | 61 70 |
| Incidence of Cases | 20 | 15 | 5 | 10 | 10 | 6 | 9 | 1 | 2 | 1 | 1 |
| Cases Following Swimming | 7 | 6 | 1 | 7 | – | 5 | 1 | | 1 | | |
| History of Pruritus or Previous Involvement | 8 | 6 | 2 | 1 | 7 | | 3 | 1 | 2 | | 1 |
| History of Trauma Picking Ear | 2 | 2 | | 1 | 1 | | 1 | | | 1 | |
| Furuncle Noted | 12 | 8 | 4 | 5 | 7 | 5 | 4 | 1 | 1 | | 1 |

## PATHOLOGIC STUDIES OF BIOPSIES

### *Histologic Characteristics of the Inflammatory Reaction*

The degree of the inflammatory reaction, as determined by the number of inflammatory cells and the basic alterations of the tissues, varied with different patients, but for the most part was moderately severe (see Fig 1) Although round cells (mostly lymphocytes) were predominant in three patients, the usual situation was a great preponderance of polymorphonuclear leukocytes (see Fig 2) These cells usually infiltrated most areas of the biopsy specimens diffusely, but in some locations they were more concentrated, occasionally around skin appendages There was no perivascular collection of the inflammatory cells

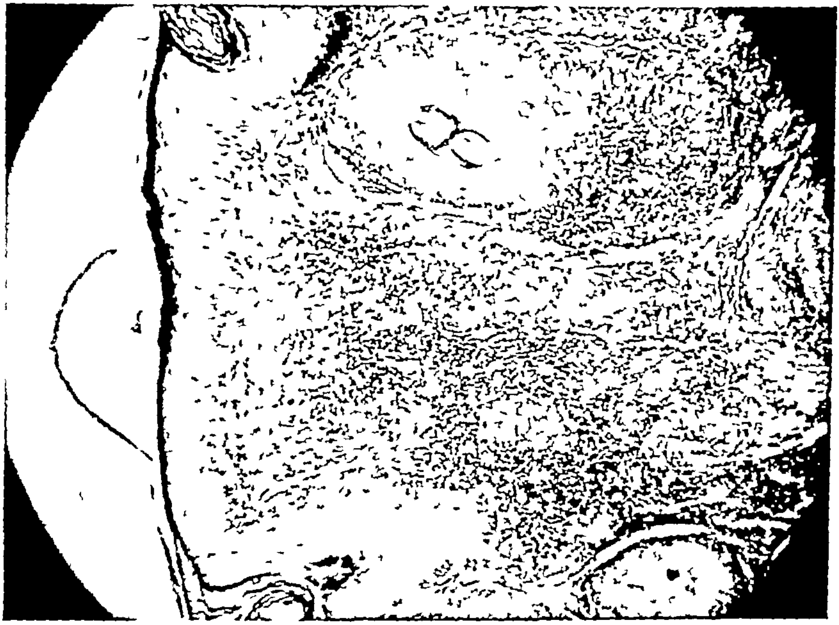

Fig 1 (E-56-67) Moderately severe inflammatory reaction in connective tissue under epidermis and around hair follicles and sebaceous glands Only a few inflammatory cells are seen in the epithelium and there is moderate parakeratosis Hematoxylin and eosin stain X-60

Eosinophils were scarce in most of the tissue sections, but in two patients these cells were significantly increased When present, the eosinophils were found throughout the inflammatory reactions

Focal tissue destruction in the dermis, with infiltration of solid sheets of neutrophilic leukocytes, was present in several patients (see Fig 3) These furuncles were relatively small and were surrounded by inflammatory cells of the type seen in other areas of the tissue in that patient A few eosinophils were present in the exudate within the furuncles in biopsy material in which those cells were present elsewhere

Gram-positive bacteria in clumps (see Fig 4), morphologically similar to staphylococci, were found deep in the tissue from two patients Similar bacteria were present in detached keratin and cellular debris in one of these biopsies and two others

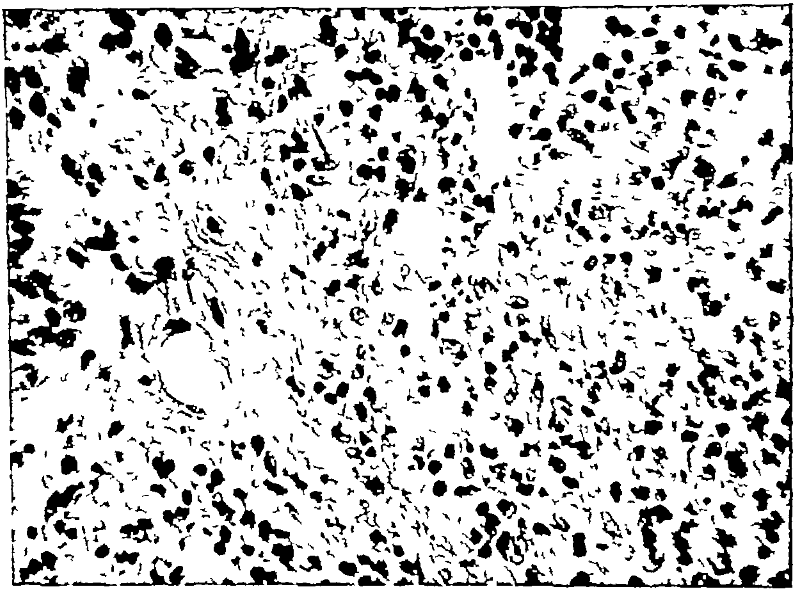

Fig 2. (E-56-67) Polymorphonuclear inflammatory cells in tissue illustrated by Fig 1. Hematoxylin and eosin stain X-330

Infiltration of the epidermis was limited to neutrophilic leukocytes and an occasional eosinophil, noted in areas of spongiosis and vesiculation (see Fig 5), or rarely within hair follicles (see Fig 6), giving the appearance of microabscesses within the epidermis, these cells also were noted in the most superficial keratin layer and in fragments of keratin debris

The material from one patient was characterized by the presence of many large multinucleated giant cells of the type commonly seen with foreign bodies Many cells of varied type were seen around these giant cells

*Epidermis*

In most of the sections there was a slight thickening of the epidermis, with some hyperkeratosis, parakeratosis, and slight hyperplasia of the basal layer Elongation of the rete pegs of a mild degree was commonly present Spongiosis (edema) of the epidermis was frequent, being absent completely in only three patients Vesiculation of varying degree was often present and, as expected, appeared to be a progression from the severe stage of spongiosis (see Fig 5) As noted previously, neutrophils and a few eosinophils were in these areas Microabscesses (see Fig 6), appearing to result from intrafollicular inflammation and quite different from the vesicula-

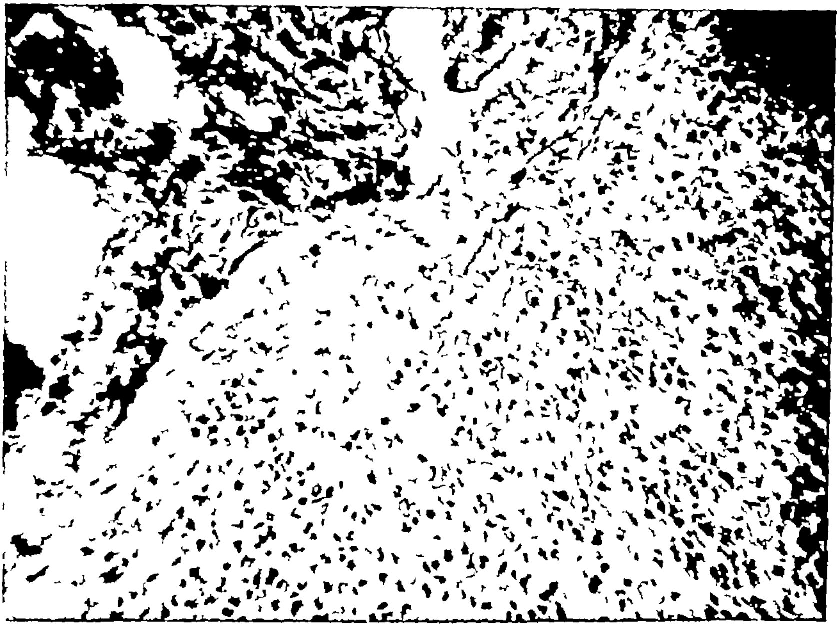

Fig 3 (E-57-111) Purulent exudate present in a furuncle Hematoxylin and eosin stain X-230

tion, were seen rarely Degeneration of the epidermis and neutrophilic infiltration were present over the furuncles Follicular hyperkeratosis was present to some extent in all of the tissue except that from one patient

*Skin Appendages*

In general the hair follicles shared the changes of the epidermis, though to a lesser degree Spongiosis and vesiculation were prominent in material from some patients and the inflammatory exudate of the dermis was occasionally concentrated about the hair follicles Neutrophils, and rarely eosinophils, were present in the areas of spongiosis and vesiculation Microabscesses within follicles have been described above

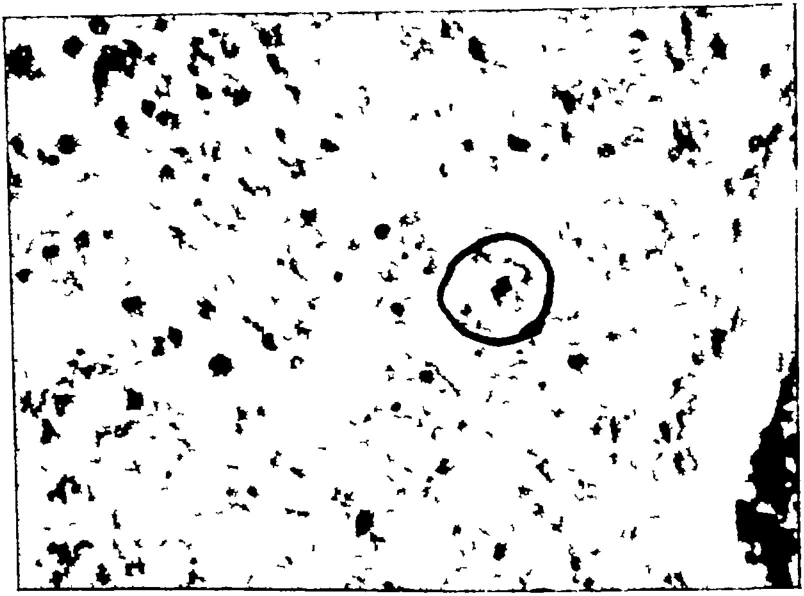

Fig 4 (E-56-185) Small clump of gram-positive cocci (upper center) deep in skin of ear Gram s stain X-450

The apocrine (ceruminous-producing) glands varied in the height of their epithelium, consistent with known variation due to secretory activity In the vicinity of the most severe inflammatory reactions the glandular epithelium was distort-

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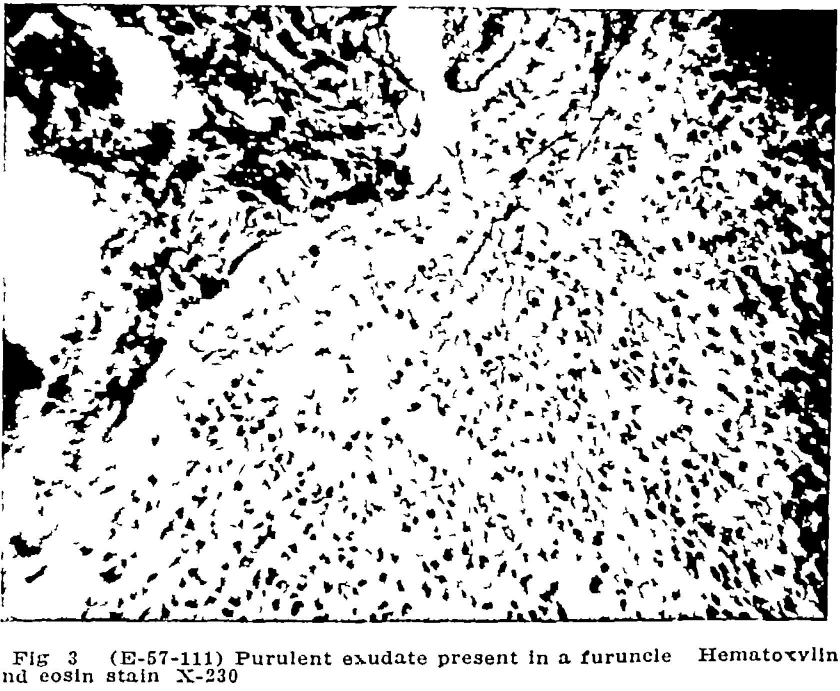

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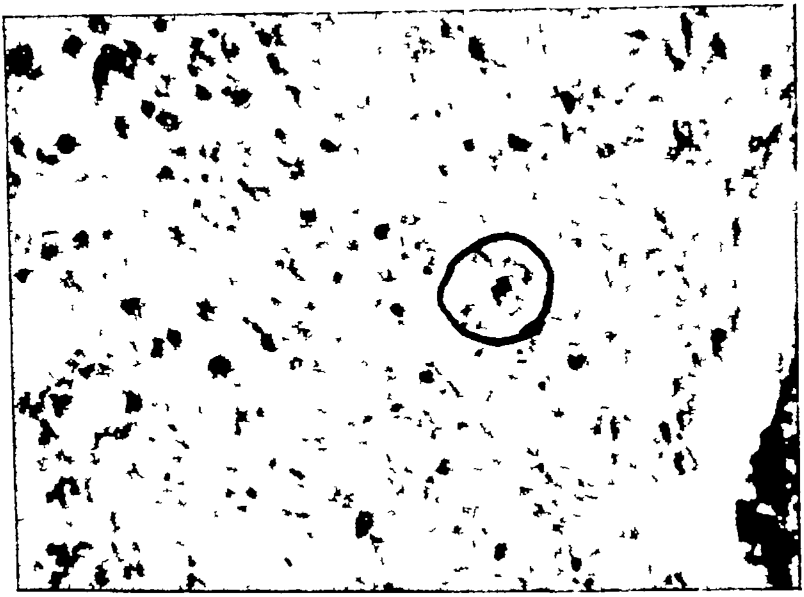

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The apocrine (ceruminous-producing) glands varied in the height of their epithelium, consistent with known variation due to secretory activity In the vicinity of the most severe inflammatory reactions the glandular epithelium was distorted, and inflammatory cells, usually only a small number, were present within the epithelium and the lumens The glands were badly damaged or destroyed occasionally in the vicinity of the most severe inflammation (see Fig 7) Dilatation of the ducts either was not present or was slight

Inflammatory cells in and around the sebaceous glands were sparse Retention of sebum was present to a slight degree in some glands

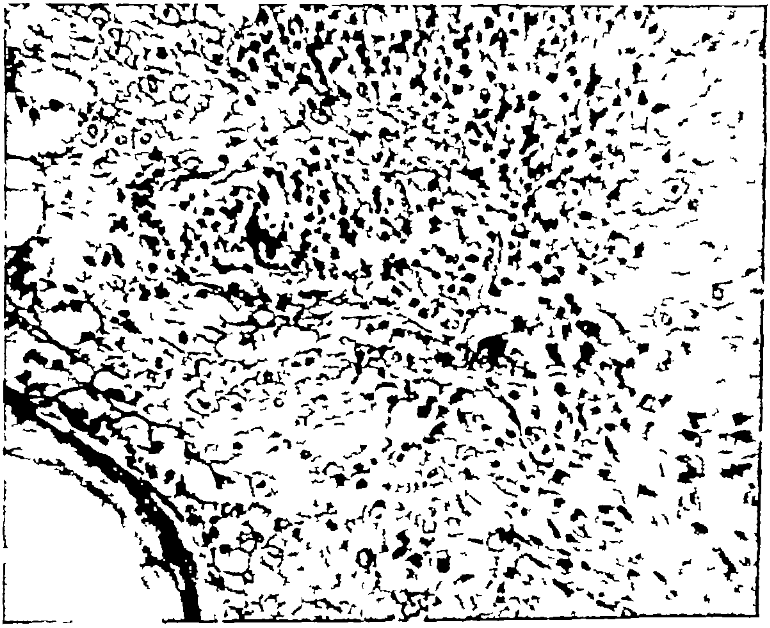

Fig 5 (E-57-136) Polymorphonuclear leukocytes in areas of spongiosis and vesiculation Hematoxylin and eosin stain X-230

### *Dermis*

The general inflammatory reaction in the dermis has been described above This was accompanied by some degree of edema in most of the material, most prominent in the upper dermis Brown pigment which gave a negative reaction to the iron stain was present in material from two patients

Dilatation of blood vessels was noted, especially in the upper dermis Endothelial swelling was prominent, varying in severity with the amount of inflammation present In some vessels the lumen was narrowed by the swollen endothelial cells No vascular thrombi were noted, necrosis of blood vessels was also absent

## HEMATOLOGIC CORRELATION

A scattergram plotting the total white counts of the peripheral blood against the percentage of neutrophils in the tissues reveals a fairly consistent finding of more than 50 per cent segmented cells in the tissues when the total count was over 10,000 A second scattergram plotting the percentage of eosinophils in the peripheral blood against the percentage of eosinophils seen in the tissues failed to reveal any correlation, comparatively few eosinophils were noted in the tissues, regardless of the percentage found in the peripheral blood

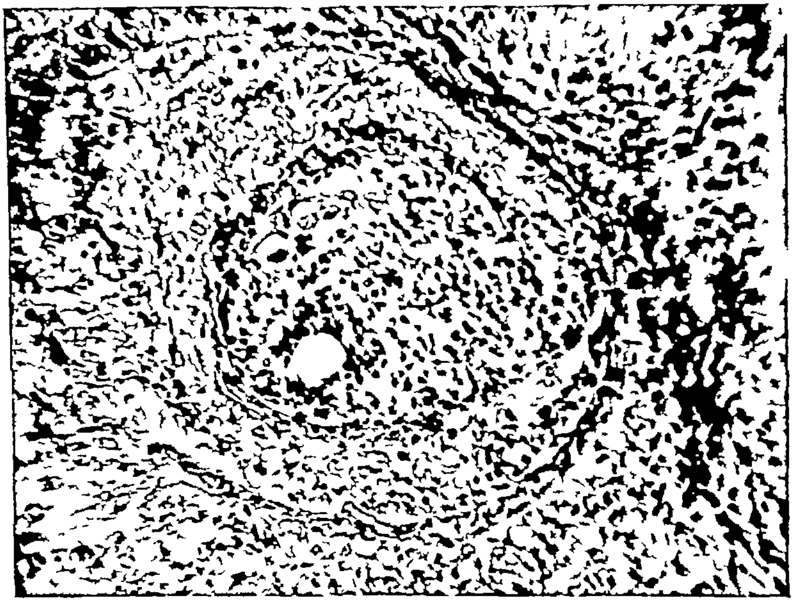

Fig 6 (E-57-136) Leukocytic infiltration of polymorphonuclear type in hair follicle Hematoxylin and eosin stain X-230

## DISCUSSION

The inflammatory reaction present in these patients differed from that described by Sophian and Senturia[4] in that there was significant tissue eosinophilia in only two specimens Furuncle formation, conspicuous in our material, was not described in their studies Sophian and Senturia also described vascular necrosis and thrombosis, neither of these changes was present in our material With the exception of tissue eosinophilia in two cases there was nothing in the histologic features of the inflammatory processes studied by us to suggest a hypersensitivity mechanism On the contrary, the features in general are those one would expect to find in an infectious process, with localization and furuncle formation in specimens from some patients It is possible that in the two patients in whom there was tissue eosinophilia the basic changes were produced by hypersensitivity, with a com-

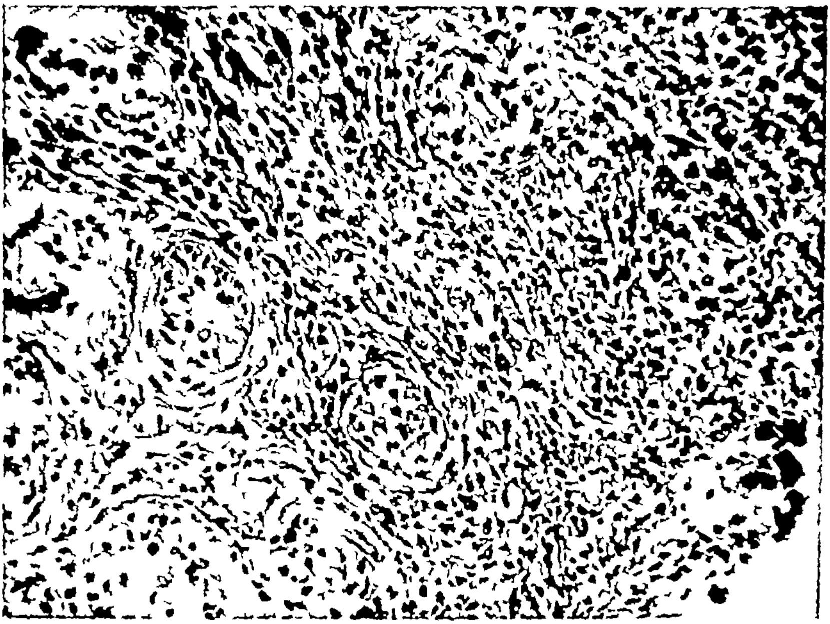

Fig 7 (E-57-107) Severe inflammatory reaction in and around apocrine glands Hematoxylin and eosin stain X-230

plicating infectious process One of these patients had a definite furuncle

Shelley and Perry,[2] in an experimental study of the effect of various materials on the human external ear, described spongiosis and vesiculation of follicles as characteristic of a low grade contact dermatitis, produced by a 1 100 acetone solution of 3-n-Penta Decyl-catechol, however, they also noted a similar change in the skin of ears treated with an irritant, 2 to 4 per cent formalin The follicular alterations described in those experiments were similar to the spongiosis and vesiculation present in the follicles of our material, in our studies, however, these changes were even more pronounced in the epidermis proper In view of the fact that spongiosis and vesiculation were produced by entirely different chemicals in their studies, and are present in a variety of skin diseases, it seems unlikely that these follicular or epidermal changes are a specific characteristic of allergic disease of the external ear

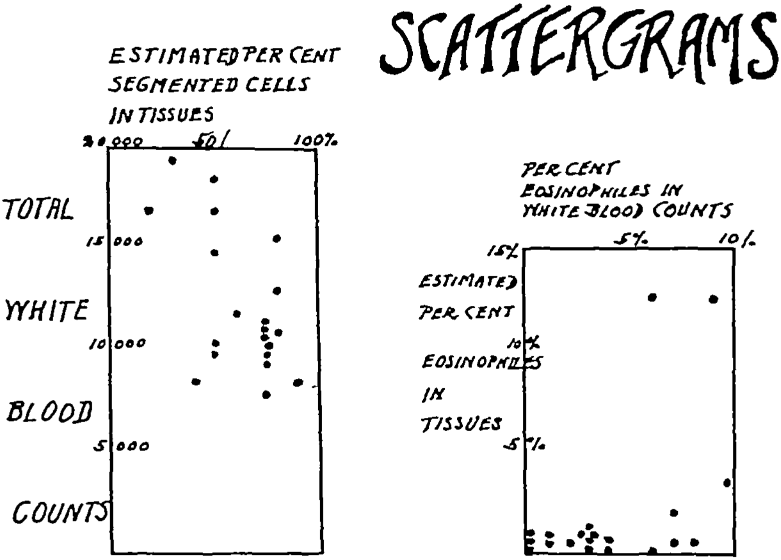

CHART 3

Vicksburg, Mississippi—Ground Elevation Above Sea Leval—234 Feet

|  | 1956 |  |  |  |  | 1957 |  |  |  |  |  |  | Average | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year and Month | A | S | O | N | D | J | F | M | A | M | J | J |  |  |
| Relative Humidity | 59 | 57 | 55 | 55 | 64 | 68 | 62 | 55 | 55 | 57 | 61 | 60 | 59 |  |
| Average Temperature | 82 3 | 75 4 | 68 9 | 55 2 | 56 9 | 49 1 | 57 8 | 56 5 | 67 0 | 73 6 | 79 1 | 82 2 | 67 |  |
| Incidence of Cases .. | 3 | 1 |  | 2 | 1 | 1 | 1 |  | 1 | 2 |  | 8 |  | 20 |
| Following Swimming .. | 3 |  |  |  |  |  |  |  |  |  |  | 4 |  | 7 |
| With Furuncles .. | 1 |  |  | 1 | 1 | 1 | 1 |  | 1 | 1 |  | 5 |  | 12 |

Statistics on humidity and temperature obtained through the courtesy of Mr Ernest Sherrill Meteorologist Weather Bureau Vicksburg

The one biopsy specimen of the present study in which a giant cell reaction was present is of interest It seems likely that they resulted from damage to sebaceous glands with loss of sebum into the tissue Although no foreign material could be demonstrated, it is possible that an unknown material had been introduced into the tissues of the ear

Humidity, temperature and swimming are currently considered important factors in the production of this type of external otitis, and these studies may add some support to this opinion The relative humidity is rather high in this area throughout the year and does not vary greatly, while there is no direct relationship between high humidity and incidence of cases, the constant high humidity may explain the incidence of cases during the Winter months Apparently higher temperatures in Summer had no influence other than to encourage swimming but, again, the average temperature in this area is comparatively high The incidence following swimming is obvious

The occurrence of furunculosis throughout the year adds support to our opinion that furunculosis is a stage in the inflammatory process of acute diffuse external otitis due to or complicated with infection by furuncle-forming bacteria

## CONCLUSION

We have presented detailed studies of the pathologic findings in 20 cases of acute diffuse external otitis due to infection, 12 of which were clinically complicated with furunculosis, and have correlated them with total and differential white blood counts

These studies have been interesting to us, but we do not consider them final in any sense The obvious differences between our findings and those of Sophian and Senturia,[4] and the known influence of temperature, humidity and exposure, adds support to the theory that the clinical picture of this type of acute diffuse external otitis may be varied in different geographical areas and climates We feel that studies from other areas are indicated, and hope that other otologists and pathologists will join us in continuing these investigations

Our appreciation is extended to Mr John Dickson, Chief, Department of Medical Illustration, University of Mississippi Medical Center, for the microphotographs used in this paper

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## POST GRADUATE COURSE
## UNIVERSITY OF ILLINOIS

The next postgraduate course in Laryngology and Bronchoesophagology to be given by the University of Illinois College of Medicine is scheduled for the period October 27 through November 8, 1958, under the direction of Dr Paul H Holinger

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# PATHOLOGY OF THREE HUNDRED CLINICALLY BENIGN LESIONS OF THE VOCAL CORDS *

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and
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Charlottesville, Va

The survey of this group of patients was prompted by Salinger's provocative article, published in THE LARYNGOSCOPE in 1956, pertaining mainly to the nomenclature of benign tumors of the larynx From the material accumulated, and the information available in the articles mentioned in the bibliography,[2-30] we have made an attempt to clarify our thinking in regard to the classification of abnormal but benign changes in the tissues of the vocal cords As will be seen, it is evident that the results of the survey will be of benefit to us, and perhaps may be of interest to others

We decided to study 300 consecutive cases (May, 1949, through May, 1957, an eight-year period), in which material was removed from the vocal cord for therapeutic and diagnostic reasons The laryngoscopies and excisions of tissue were performed by members of the Department of Otolaryngology, of the University of Virginia Hospital, except in two instances (tissue referred by otolaryngologists in neighboring cities) , and all the material was examined by the members of the Department of Pathology of this institution A number of individuals participated in the above procedures, and this is one of the reasons for the confusion that was apparent in the presentation of the material to the pathologists and in the reporting of the results of their examinations

As will be noted, the survey was initiated by first review-

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*Read at the meeting of the Southern Section American Laryngological Rhinological and Otological Society Inc Memphis Tenn. Jan 24 1958

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ing the various interpretations of the tissues, as reported by the first pathologists, who were the ones designated to be the examiners of all the routine specimens received by the Department of Pathology at that particular time Consequently, the material was analyzed by many different pathologists of varying grades of experience in studying laryngeal structures It was shown, also, that this group seldom received an adequate clinical description of the section to be examined In the majority of cases the pathologist was aware only that the specimen was taken from the vocal cord

TABLE I—CLINICAL DIAGNOSIS

| | | |
|---|---|---|
| 1 | Undiagnosed (Tissue from Vocal Cord) | 97 |
| 2 | Polyp | 57 |
| 3 | Papilloma | 26 |
| 4 | R O Carcinoma | 25 |
| 5 | Granuloma | 24 |
| 6 | Juvenile Papilloma | 12 |
| 7 | Vocal Cord Nodule | 11 |
| 8 | Leukoplakia | 10 |
| 9 | Cyst | 8 |
| 10 | Laryngitis (Inflammation) | 7 |
| 11 | Singers' Nodule | 5 |
| 12 | Hyperkeratosis | 4 |
| 13 | Hemangioma | 4 |
| 14 | Benign Lesion | 4 |
| 15 | Keratosis | 2 |
| 16 | Mucosa | 2 |
| 17 | Ulcer (Inflammation) | 1 |
| 18 | Fibroma | 1 |

This inadequacy is demonstrated in the details of the first Table, entitled, "Clinical Diagnosis" The form accompanying the section was usually completed by an assistant junior resident, the accurate record of the senior staff physician not being available This was mainly true in regard to the earlier patients in the group, the defection having been corrected later

Referring again to Table I, "Clinical Diagnosis," one will notice a large number in the undiagnosed category The tissue was sent to the pathologist with very meager details concerning the history, plus the notation only that it was from a vocal cord Further examination of this chart shows other evidences of lack of detail and care in stating the preoperative clinical diagnosis

Next, reference is directed to Table II, entitled, "Initial Pathological Diagnosis" One is impressed immediately by the numerous diagnoses made, and also by the similarity and minor variations in many of them These differences may be attributed in part to the lack of close contact between the laryngologist and the pathologist, in addition to the fact that the pathologist's interest was more general than specific as far as abnormal laryngeal tissues were concerned

TABLE II—INITIAL PATHOLOGICAL DIAGNOSIS

| | | |
|---|---|---|
| 1 | Polyp | 81 |
| 2 | Papilloma | 42 |
| 3 | Singers Nodule | 36 |
| 4 | Granuloma | 23 |
| 5 | Laryngitis (Inflammation) | 17 |
| 6 | Squamous Hyperplasia | 13 |
| 7 | Juvenile Papilloma | 11 |
| 8 | Granulation Tissue | 10 |
| 9 | Inflammation with Hyperplasia | 10 |
| 10 | Cyst | 9 |
| 11 | Hemangioma | 8 |
| 12 | Hyperkeratosis with Inflammation | 5 |
| 13 | Hyperkeratosis | 4 |
| 14 | Inflammation with Metaplasia | 4 |
| 15 | Dyskeratosis with Metaplasia | 3 |
| 16 | Hyperplasia with Metaplasia | 3 |
| 17 | Leukoplakia | 2 |
| 18 | Dyskeratosis | 2 |
| 19 | Hyperkeratosis with Hyperplasia | 2 |
| 20 | Fibrosis with Myxomatous Degeneration | 2 |
| 21 | Pachydermia | 2 |
| 22 | Myofibroma | 2 |
| 23 | Edema | 2 |
| 24 | No Pathological Change | 2 |
| 25 | Inflammation with Myxomatous Degeneration | 1 |
| 26 | Hyalinization with Myxomatous Degeneration | 1 |
| 27 | Hyperkeratosis with Myxomatous Degeneration | 1 |
| 28 | Hyperkeratosis with Cyst | 1 |
| 29 | Hemorrhage in Muscle Fibers | 1 |

The same sections presented in Table II were re-examined by a pathologist (D S ), who was specially interested in the subject of abnormal laryngeal tissue and its problem of nomenclature An attempt was made to re-analyze the entire

TABLE III—REVISED PATHOLOGICAL DIAGNOSIS

| | | | |
|---|---|---|---|
| 1 | Laryngeal Nodules | | 134 |
| | Unqualified | 128 | |
| | Qualified | | |
| | With Hemosiderosis | 2 | |
| | With Hyperkeratosis | 2 | |
| | With Granulomatous Features | 1 | |
| | With Inflammation | 1 | |
| 2 | Inflammation | | 34 |
| | Unqualified | 10 | |
| | Qualified | | |
| | With Granulation Tissue | 13 | |
| | With Hyperkeratosis | 8 | |
| | With Ulceration | 2 | |
| | With Ulceration and Granulation Tissue | 1 | |
| | (No cases of Specific Inflammation such as Tuberculosis, Blastomycosis, Syphilis, etc , included) | | |
| 3 | Squamous Papillomas | | 28 |
| | Unqualified | 26 | |
| | Qualified | | |
| | With Dyskeratosis | 2 | |
| | (Includes Juvenile Papillomas) | | |
| 4 | Laryngeal Polyps | | 27 |
| | Unqualified | 18 | |
| | Qualified | | |
| | With Hyperkeratosis | 1 | |
| | With Dyskeratosis | 1 | |
| | Fibrous (Papillomas) | 5 | |
| | Fibrous with Hyperkeratosis | 2 | |
| 5 | Epithelial Changes | | 25 |
| | Unqualified | | |
| | Qualified | | |
| | Hyperkeratosis | 19 | |
| | Dyskeratosis | 2 | |
| | Carcinoma in Situ | 2 | |
| | Epidermoid Carcinoma | 1 | |
| | Hyperplasia | 1 | |
| 6 | Cysts | | 12 |
| | Unqualified | 4 | |
| | Qualified | | |
| | Columnar | 4 | |
| | Mucous | 3 | |
| | Squamous | 1 | |
| 7 | Pyogenic Granuloma | | 10 |
| | Unqualified | 10 | |
| 8 | Miscellaneous | | 30 |
| | Missing Specimens | 15 | |
| | Inadequate Specimens | 9 | |
| | Normal Mucosa | 3 | |
| | Hemangioma | 1 | |
| | Skin (error) | 1 | |
| | Nodular Lymphoid Infiltration (Lymphosarcoma) | 1 | |

group of 300 sections Fifteen specimens could not be located and were classified as missing in the miscellaneous category

The interpretations of this pathologist, working intimately with the laryngologists, offered an interesting study of the two groups, as recorded in Tables II and III These studies have resulted in a simpler rearrangement or classification of abnormal benign laryngeal lesions, which, we are hopeful, will be of value to our local laryngologists and pathologists in the future, perhaps also, benefit, as far as prognosis and treatment are concerned, may be forthcoming as a result of this arrangement

One may have noticed that in the collection of cases in this survey, no malignant neoplasms nor specific inflammatory processes of the mucous membranes are included Many carcinomas and a few cases of specific inflammatory lesions of the cords, such as tuberculosis and blastomycosis, were encountered during the years of the survey, but were eliminated, as our primary interest was in benign lesions with little specificity It was noted that apparently carcinoma of vocal cords was comparatively easy to diagnose, as when this diagnosis was made clinically, prior to histological examination, it was usually correct In turn, when doubt was exhibited by the request, "Rule out carcinoma," sent to the pathologist with the tissue, carcinoma was generally not present

TABLE IV—COMPARISON COMMONER LESIONS

| Diagnosis | Original Path. Diag Number | Revised Path. Diag Number |
|---|---|---|
| 1 Polyps | 81 | 27 |
| 2 Papillomata (Adult and Juvenile) | 53 | 28 |
| 3 Singers Nodules (Laryngeal) | 36 | 134 |
| 4 Granulomata | 23 | 10 |
| 5 Inflammations (Laryngitis) | 14 | 34 |

As will be seen later, the pathologists had little difficulty in deciding upon the diagnosis of carcinoma, for in the approximately 300 examinations, only one fairly definite error in diagnosis was disclosed One specimen was called benign, but on second examination was thought to be unquestionably an epidermoid carcinoma

Some comments will now be made with regard to the various categories used in the classification Space does not permit a detailed study of all, only the commoner groups will be considered

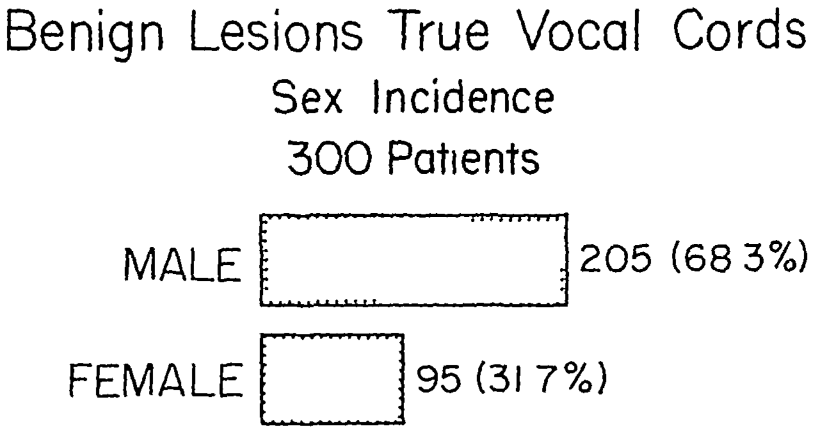

Fig 1

## LARYNGEAL NODULES (VOCAL NODULE, SINGERS' NODE, CHORDITIS NODOSA, SCREAMERS' NODE, FIBROUS NODULE, CHORDITIS TUBEROSA, TEACHERS' NODE, ETC

In the initial pathologic diagnosis (Table II), 36 patients were considered to have singers' or laryngeal nodules When the same group of cases were re-examined by the second pathologist and laryngologist, the number in this category was increased to 134 patients, as will be noted in Table III This is not particularly surprising, as there is much confusion in the nomenclature and histological interpretation of tissue from the vocal cords which may be classified as laryngeal nodules or laryngeal polyps For instance, Stewart[1] does not mention laryngeal nodules in his 104 cases of benign tumors of the larynx, but does have 61 cases of "Inflammatory Polypus" Epstein[2] and his associates diagnosed 283 cases of laryngeal polyps in a group of 366 benign tumors, believing polyps, nodules, and polypoidal degenerations to be histologically identical non-neoplastic swellings of the membranous vocal cords. Salinger,[1] on the other hand, found that his pathologists diagnosed no polyps and only three vocal nodules in a series of 232 consecutive laryngeal biopsies. Undoubtedly, in our survey, Epstein and Stewart would have classified the majority of our nodular cases as polyps. There are many variants of nodules and polyps which may be placed in either class, depending upon the impression of the pathologist, and which are essentially different manifestations of one and the same condition. From our study, we must consider the laryngeal nodule as the commonest chronic benign lesion of the vocal cords for which tissue is removed for diagnostic and therapeutic measures.

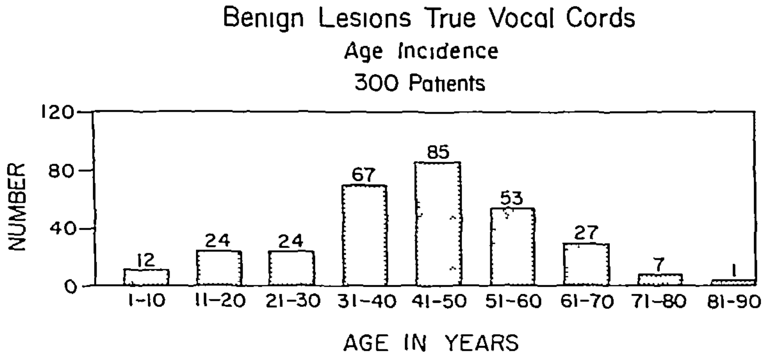

Fig 2

A laryngeal nodule is a "specialized reaction to trauma" (Ash[6]), which is basically a localized nodular or polypoid area of degeneration of the lamina propria. These reactions of degeneration include fibrosis, edema, a myxoid appearance, fibrinous deposits, and even hemorrhage, necrosis and calcification. The overlying epithelium may be atrophic or slightly hypertrophic and hyperkeratotic. Kelly and Craik,[7] Ash and Schwartz,[8] have described these variations in some detail. We have followed their descriptions to a large extent in an effort to attain histological accuracy and simplicity. The edematous, fibrous, angiomatous and myxomatous characteristics are shown in the photomicrographs.

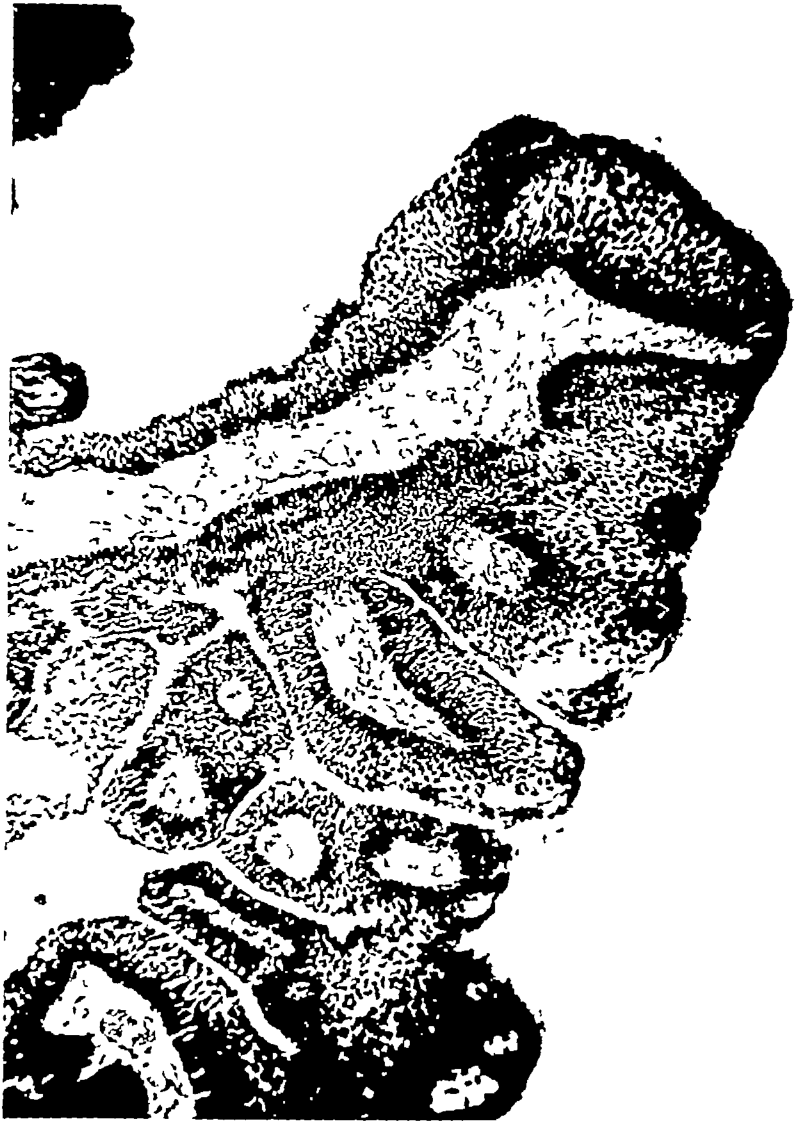

Fig. 3. Squamous papilloma of the larynx with redundant papillae of acanthotic squamous epithelium over a delicate and rather scanty stalk of fibrous tissue (H and E ×110)

## LARYNGEAL POLYPS

As in many of the categories proposed in our survey, again there were differences in the interpretation of the tissue presented to the pathologist, as far as the entity, laryngeal polyp, was concerned In the first group examined (Table II), 57 cases were diagnosed as laryngeal polyps This number was reduced (see Table III) to 27 cases when the tissues were re-examined Some were transferred to the laryngeal nodule category In some classifications, the laryngeal polyp is considered a stage in the development of the laryngeal nodule, and vice versa

We have used this term for lesions that are polypoid, or projecting masses, composed principally of a central core of fibrous connective tissue of greater density than normal lamina propria and covered by a normal or only slightly hyperplastic or hyperkeratotic epithelium The origin is from the subepithelial or Reinke's spaces It seems to contrast with the papilloma, in that the stroma is predominant in the polyp, while the epithelium is predominant in the papilloma Although the first stage (Ash) of the laryngeal nodule consists of subepithelial fibrosis, the early laryngeal nodule is not polypoid and, therefore, differs from this lesion we are calling a polyp Polyps are pedunculated and may exhibit angiomatous and myxomatous characteristics Polypoid degenerative changes are diffuse and sessile, and are sometimes described as laryngeal nodules

## INFLAMMATIONS

The nonspecific chronic inflammatory group, numbering 34 cases, offered much less confusion and difficulties in the pathologic diagnosis than those classes previously considered The histologic signs of inflammation are quite evident, and the number of cases of laryngitis with the various qualifications are similar to Tables II and III

## SQUAMOUS PAPILLOMATA

The larger number of papillomata were so designated by the pathologist who performed the initial examinations After

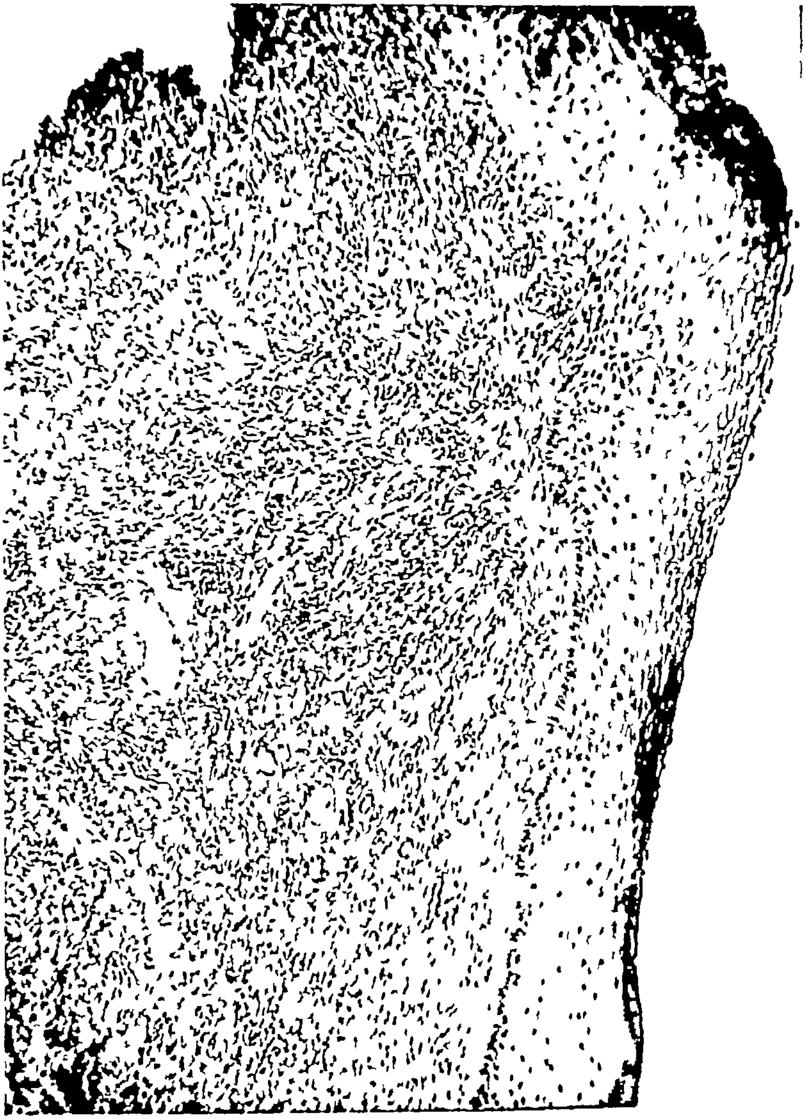

Fig 1 Pyogenic granuloma of the larynx composed of a celular granulation tissue with hemosiderin under a slightly hyperplastic and hyperkeratotic epithelium (H and E (110X)

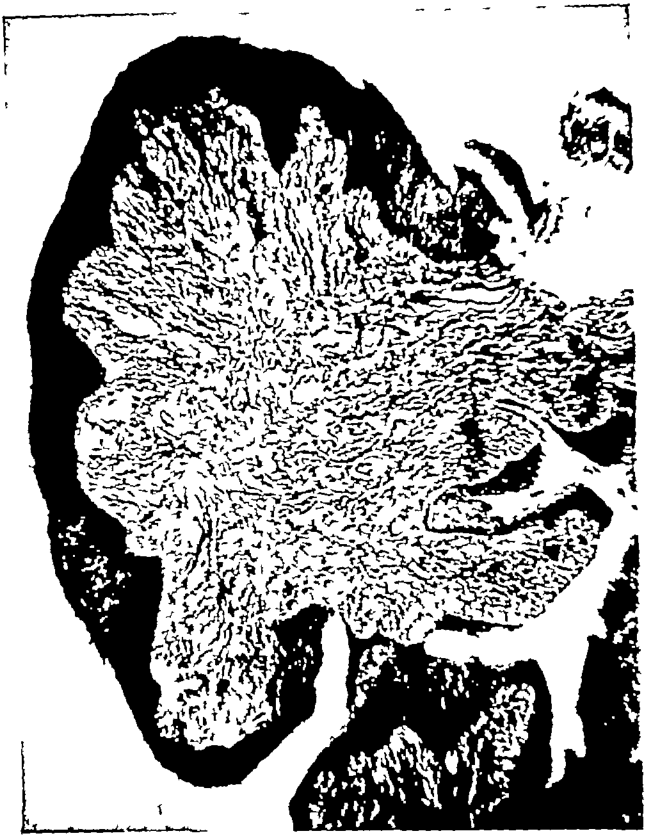

Fig 5 Polp of the larynx with pedunculated configuration dense fibrous stroma and only slightly thickened or hyperkeratotic overlying squamous epithelium This lesion is not as characteristically papillary in outline as is the papilloma (H. and E 60X)

further consideration, according to the scheme previously outlined, the number in this section was reduced, with differences favoring mainly the nodular group

The histological diagnosis was made on the basis of a papillary lesion, either pedunculated or sessile, composed of thick folds of hyperplastic, acanthotic, squamous epithelium, arranged over delicate, thin cores or processes of vascularized connective tissue, essentially similar to normal lamina propria In view of our present knowledge, cases of this lesion can be divided, clinically but not histologically, into

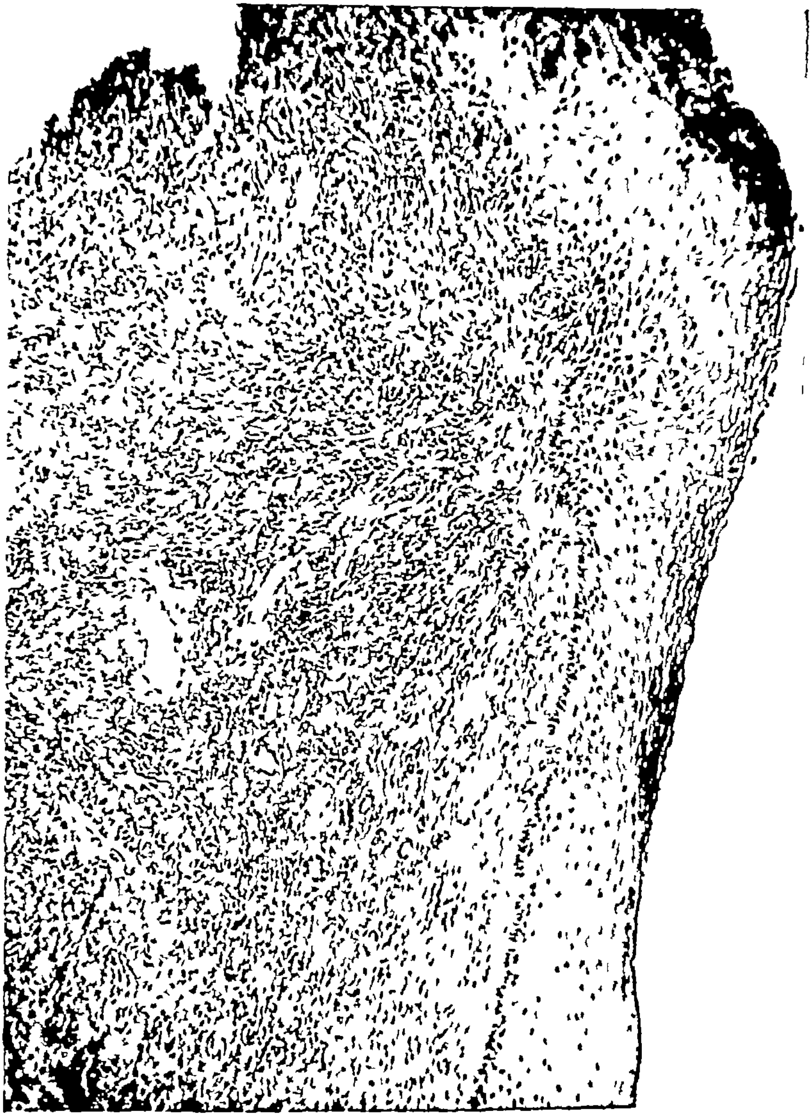

Fig 4 Pyogenic granuloma of the larynx composed of a celular granulation tissue with hemosiderin under a slightly hyperplastic and hyperkeratotic epithelium (H and E (110X)

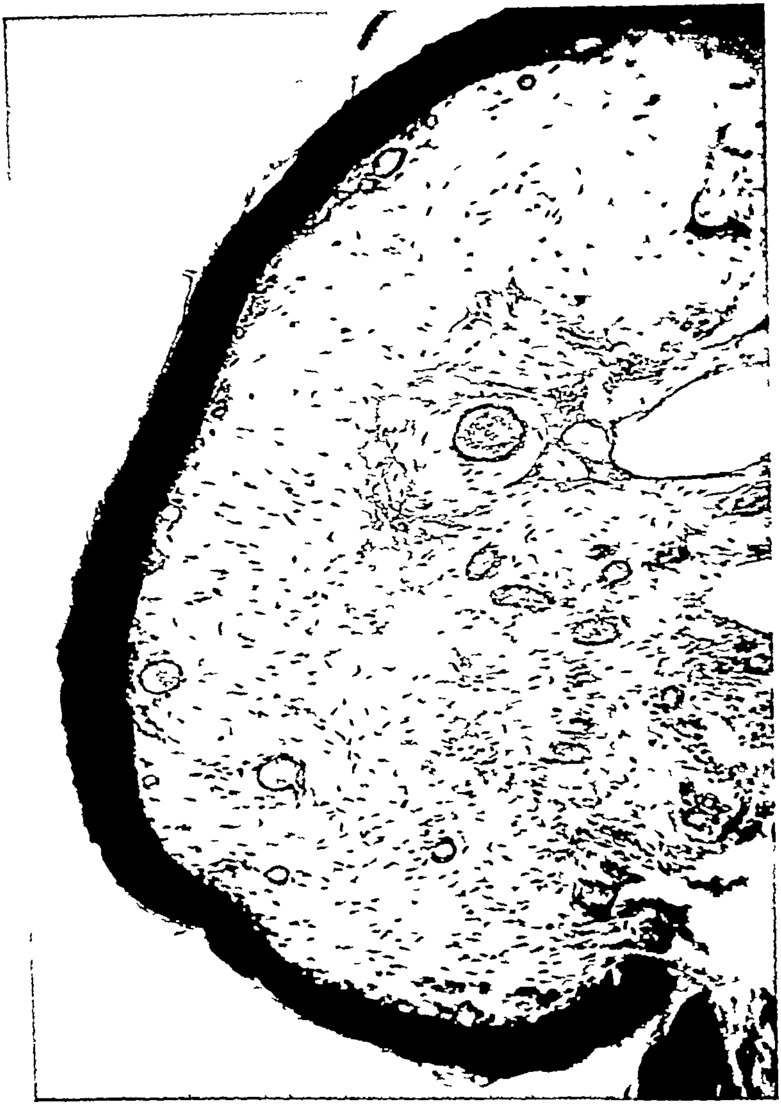

Fig 7 Laryngeal nodule probably in an early phase showing edematous stroma small angiectasis and small amounts of fibrinoid strands in the stroma. The epithelium is slightly hyperkeratotic (H and E 110X)

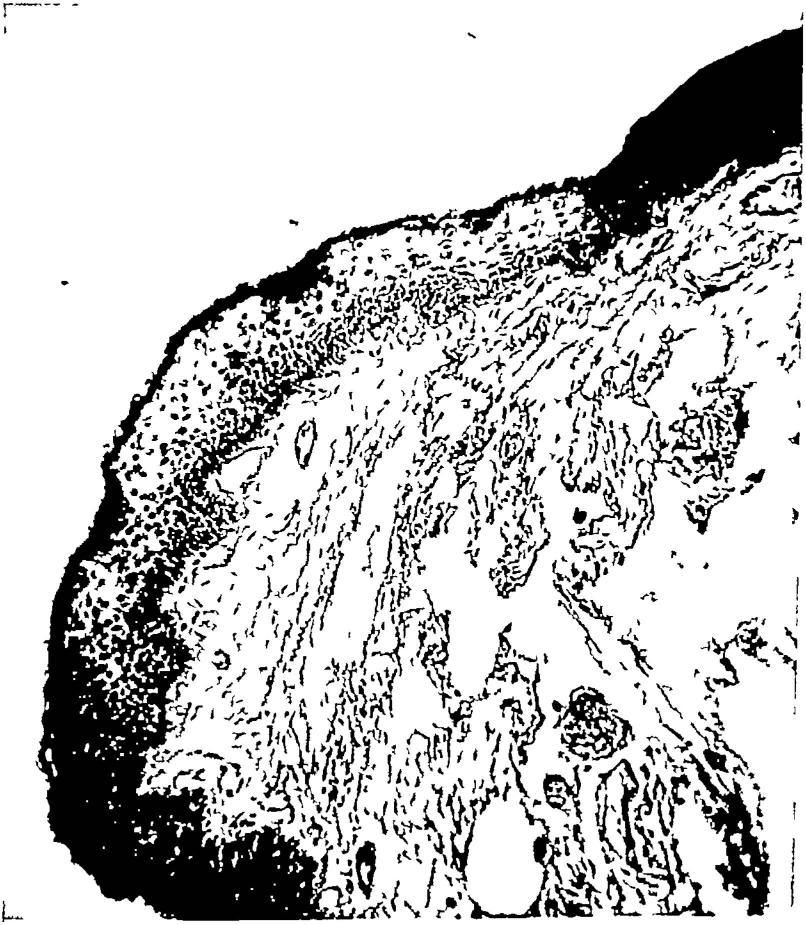

Fig 6 Laryngeal nodule with angiectasis myxoid stroma coarse fibrinoid strands in the stroma particularly about the dilated blood vessels or lymphatics and hyperkeratotic epithelium (H and E 110×)

juvenile and adult forms These are tumors of epithelial origin

## EPITHELIAL CHANGES

This is a division which, in any table of classification, could receive a wide variety of cases In the first group examined, approximately 40 specimens were reported as showing some type of abnormal epithelial changes Upon

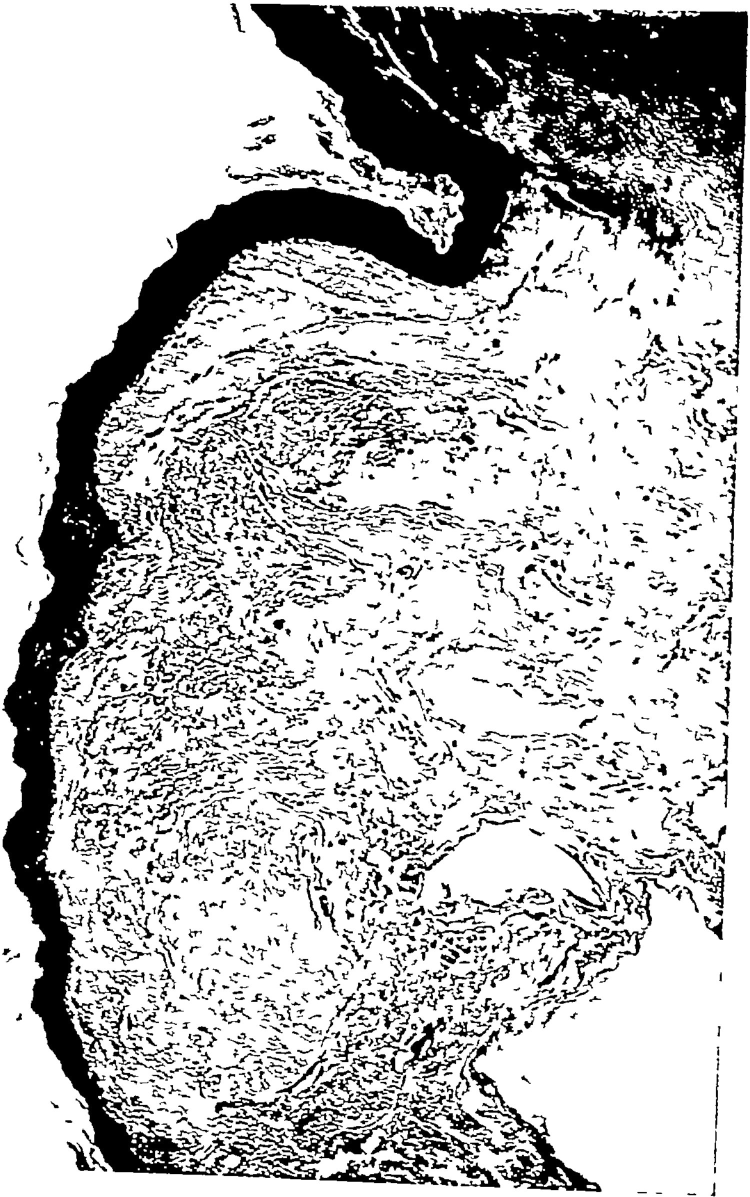

Fig 8 Laryngeal nodule probably in a late phase with extensive fibrinoid and fibrous transformation of the stroma and hyperkeratosis of the epithelium (H. and E 110×)

re-evaluation, the number, as will be noted, was reduced to 25

Hyperplasia, hyperkeratosis (hyperkeratinization) and dyskeratosis are not uncommon laryngeal conditions Many of the less severe cases undoubtedly never come to biopsy We do not believe that one sees the advanced dyskeratosis or leukoplakia of the vocal cord that one finds in the intraoral cavity Epithelial changes of the mucosa of the vocal cords deserve the most careful scrutiny, and material should be removed for histological examination without procrastination Such measures will eventually disclose an early carcinoma

The two lesions secondarily designated as carcinoma *in situ* were either erroneously diagnosed or the carcinoma was removed as an excisional biopsy, for prolonged follow-up examinations have revealed no subsequent malignant developments In the case of tissue diagnosed as frankly epidermoid carcinoma, we have not been so fortunate in our follow-up Although all efforts were exhausted in attempting to obtain further information about this patient, these were without success

## CYSTS

The diagnosis of cyst was apparently not difficult, pathologically There was general unanimity of opinion in the examinations of the specimens

## PYOGENIC GRANULOMATA

The granulomata, approximately 23 in number initially, after the revisional examination, became a group composed of only ten cases, the inflammatory category gaining therefrom

The appearance of these growths was that of a localized, nodular, and commonly polypoid mass of granulation tissue, containing many capillaries, in a stroma of young fibroblasts It is usually heavily infiltrated by histiocytes, and may contain an appreciable number of granular leukocytes The overlying epithelium is customarily intact and hyperplastic, sometimes to the point of pseudoepitheliomatous hyperplasia

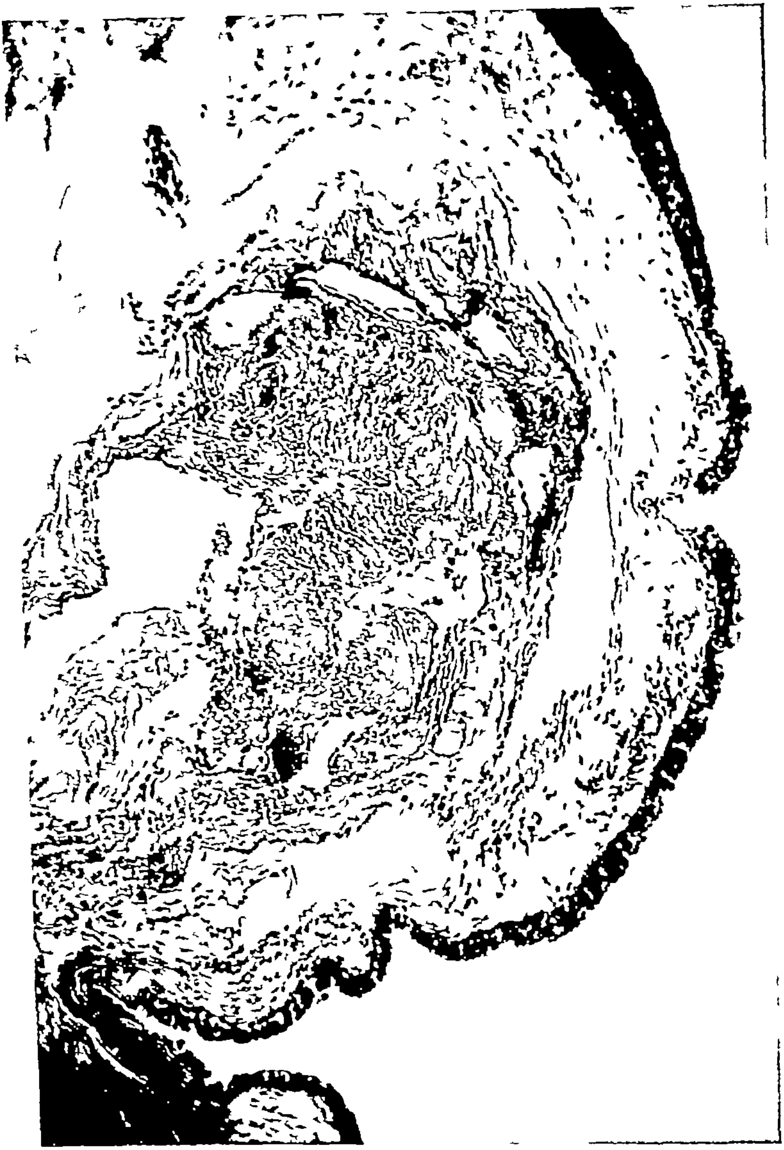

Fig 9 Laryngeal nodule with large fibrinoid mass resembling an organizing thrombus (H and E. 110X)

It differs from ordinary granulation tissue, which is frequently in an area of ulceration, showing superficial necrosis and intense, acute inflammation

## MISCELLANEOUS GROUP

Of the original 300 sections, 15 were found to have been misplaced or misfiled, and could not be located for this study The second pathologist considered the tissue of nine specimens inadequate for diagnosis, and these were rejected for further consideration The corrected number of cases re-examined was 276, and it is gratifying that "normal mucosa" was reported in only three instances One true hemangioma was present The section of skin was obviously labeled improperly The case of lymphoid nodular infiltration has been followed for several years, and there has been no subsequent evidence of lymphoma or leukemia

## COMMENTS AND SUMMARY

A consecutive series of 300 specimens of tissue removed from the vocal cords of the same number of patients were examined histologically by two or more pathologists The sections were collected over an eight-year period, ending May, 1957 Only benign lesions were analyzed, and no consideration was given to the oft-raised question as to whether benign overgrowths of subepithelial structures should be designated as "true tumors" or not No cases initially diagnosed as carcinoma were studied in this survey

The first analysis was carried out by pathologists who were genuinely interested, but not specifically, in laryngeal specimens The second examiner was one who showed particular interest in this type of tissue For various reasons, the second pathologist had the opportunity of reporting on only 285 sections rather than the 300 available to the initial group of examiners

The sex incidence indicated 68 3 per cent of the patients as males and 31 7 per cent females, with the highest age incidence being in the 41 to 50-year group

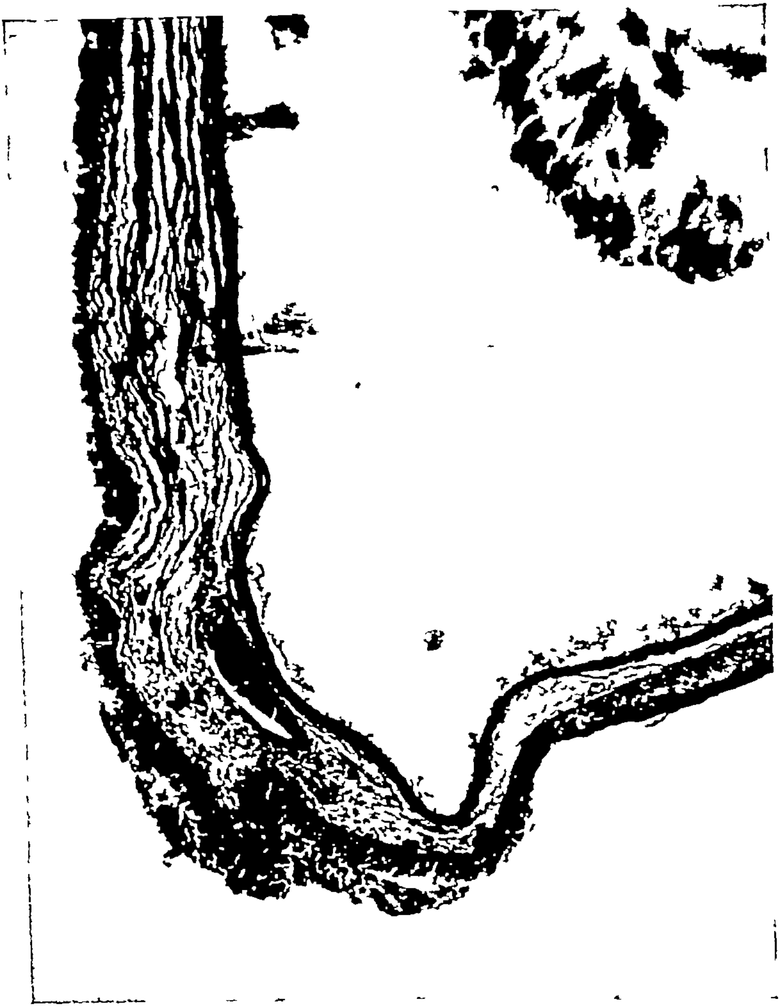

Fig 11 Laryngeal cyst lined by cuboidal or simple squamous epithelium (H. and E 110X)

upon the opinion of different pathologists Some have considered a laryngeal polyp as a stage in the development of a nodule, and vice versa, not two clinical entities The reason for this is apparent, as there are many variations in the histological appearances of these lesions, particularly in laryngeal nodules when degenerative changes have occurred That

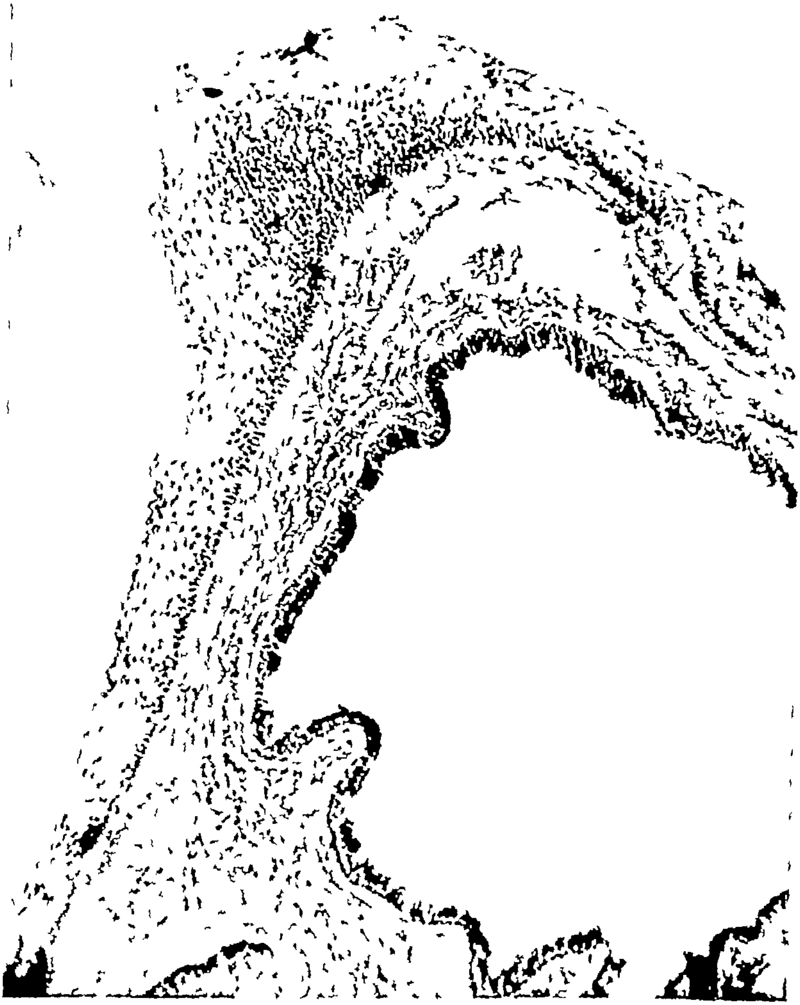

Fig 10 Laryngeal cyst lined by columnar epithelium The overlying squamous epithelium is slightly hyperkeratotic (H and E 110X)

From our own material and that available in the literature, there is obviously much confusion in the nomenclature and histological interpretation of benign specimens from the vocal cords This is especially true of lesions arising from the subepithelial connective tissue layers (Reinke's space), which have been designated as nodules or polyps, depending

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## AMERICAN ACADEMY OF OPHTHALMOLOGY AND OTOLARYNGOLOGY HOME STUDY COURSES

The 1958-1959 Home Study Courses in the basic sciences related to ophthalmology and otolaryngology, offered as a part of the educational program of the American Academy of Ophthalmology and Otolaryngology, will begin on September 1 and continue for a period of ten months Detailed information and application forms may be secured from Dr William L Benedict, the executive secretary-treasurer of the Academy, 15 Second Street, S W, Rochester, Minnesota Registrations should be completed before August 15 we can always histologically differentiate exactly between the two is certainly not clear It would seem possible that the laryngologists and pathologists interested in this subject could establish a certain criterion for distinguishing between the two, which could be used to dispel the confusion that exists in the identification of these benign vocal membranous changes

No definitive classification is attempted, because clinically it is difficult to do this, as there is so little difference in the appearance and conduct of many of the lesions Again, from our survey, we must conclude that this same difficulty is experienced by the pathologist In lieu of a classification, we have placed the results of our examinations in certain groups which will be helpful to us in clarifying the subject in the future

Certainly, one admonition is recommended, namely, "laryngologist, know your pathologist" It is obviously desirable that the laryngologist, in turn, supply the pathologist with more detailed information about the gross appearance and characteristics of the tissue to be examined

The accompanying photomicrographs illustrate some of the examples of the specimens described, and Table IV shows a comparison between the commoner lesions seen by the first pathologist with the revision in the diagnosis by the second

Finally, in summarizing, it appears that the vocal cord lesions which seem to be the most confusing to all are the laryngeal nodule, polyp, and possibly the papilloma Fundamentally, we consider the nodule as being an overgrowth of tissue containing an abnormal tunica propia, due to various degenerative changes, with an essentially normal surface epithelium The polyp is an overgrowth of tissue with an increase in quantity of a normal, or near normal, appearing tunica propia with no degenerative changes and an essentially normal epithelium These two lesions are of subepithelial origin The papilloma is a tumor containing a normal tunica propia, but an abnormally broad hyperplastic epithelial surface which may show other minor metaplastic changes

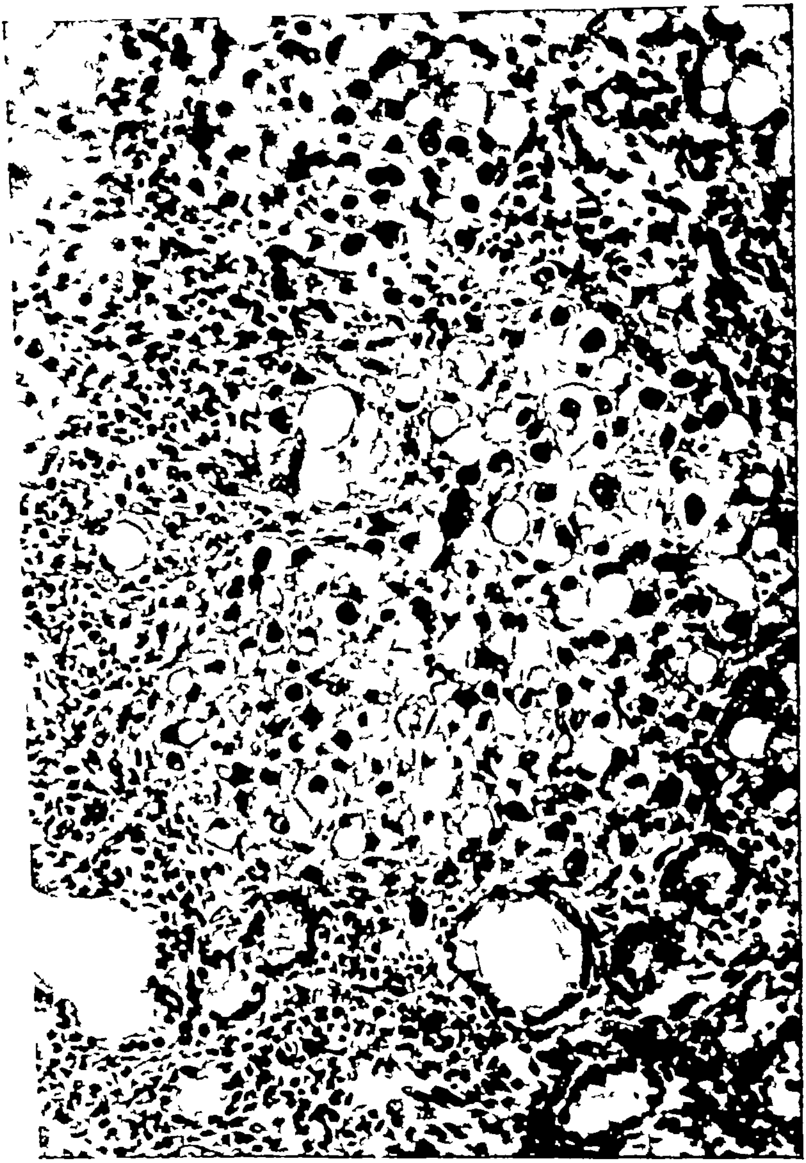

Fig 1 Medullary squamous cell carcinoma of Grade IV malignancy with extensive anaplasia and nuclear degeneration There were marked poikilocytosis and anisocytosis with hydropic degeneration of protoplasm The characteristic feature above all others was a very active lymphoid reaction (Reproduced by permission of Arch of Otolaryngology )

# CANCER OF THE LARYNX

## Report of an Advanced Case Surviving 22 Years

ARTHUR E HAMMOND, M D,

Detroit, Mich

In a previous article* the author reported on a series of 15 cases of carcinoma of the larynx which were analyzed from the point of view of age and sex incidence, etiology, classification, symptom complex, histologic grading and especially the various forms of surgical procedures It was stated at that time that radiation therapy—besides being the method of choice in extrinsic carcinoma of the larynx—may prove of definite value in some advanced intrinsic carcinomas of the larynx having a high index of malignancy with glandular metastases

The present brief communication is a report of Case II of that series, which in 1935 was referred for radiation therapy because of the advanced clinical stage of the lesion, and particularly since the histopathologic examination indicated a Grade IV index of malignancy The patient has now survived, enjoying good health, for a period of 22 years

### REPORT OF A CASE

The patient an adult white male forty seven years old, was seen at the office on September 20, 1935 complaining of difficult breathing The history was that of progressive hoarseness over a period of five months with recent painful swallowing, difficult breathing and a weight loss of 12 pounds

Indirect laryngoscopic examination revealed a large fungating tumor mass apparently arising from the right vocal cord which was fixed There was one large soft, freely movable lymph node in the right supraglottic area and two smaller soft and freely movable lymph nodes in the left supraglottic area

The patient was admitted to Harper Hospital and direct laryngoscopy was performed on September 21 1935 under local anesthesia The epiglottis was edematous A large bleeding fungating mass covered the right vocal cord with some involvement of the left vocal cord The right vocal cord was fixed Biopsy was taken from both vocal cords

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On September 22 1935 a low tracheotomy was performed under local anesthesia and because of the extensive nature of the lesion the patient was referred for radiation therapy

Between Sptember 24 1935 and March 10 1936 three series of super voltage Roentgen therapy were given with 500 kv (constant) 7 mm. Cu filter corresponding to a half value layer of 9 mm. Cu. The fractionated protracted technique was used the total cumulated dose on the pathologic areas being 7 000 r

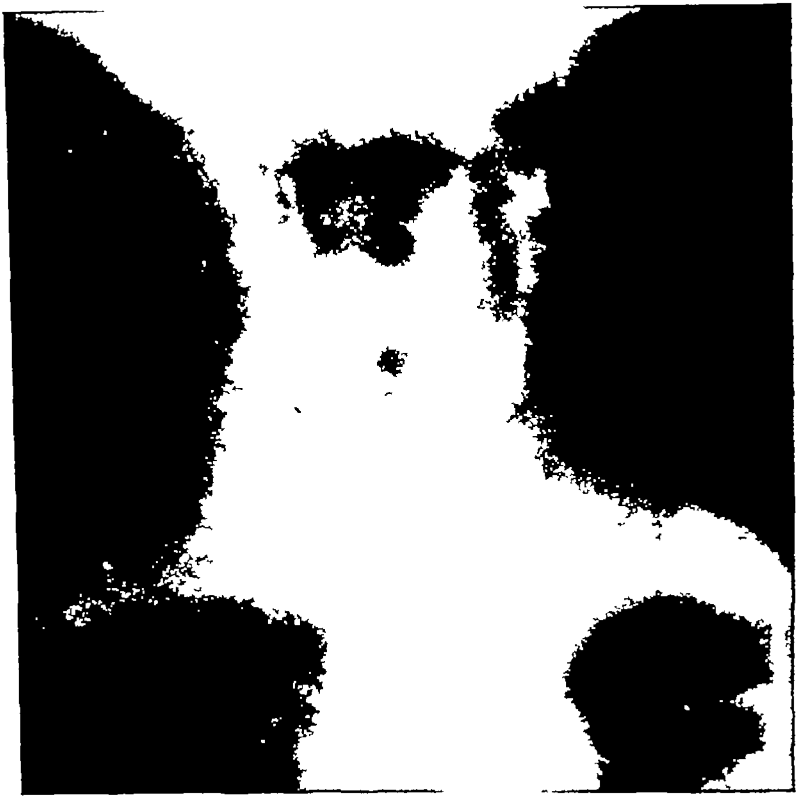

Fig 3 Laminagram in the coronal plane shows the tracheotomy tube in place There is a marked distortion of the glottic folds on the two sides particularly on the left, but with the patient phonating the letter e a fairly good apposition of the vocal cords was obtained and the Morgagni space appeared fairly normal in contour

November 17 1935 Tracheotomy tube was removed and the opening closed spontaneously

There was a satisfactory response to the radiation therapy and subsequent periodic follow up examinations gave the following findings

September 5 1940 The patient has gained five pounds in weight. He

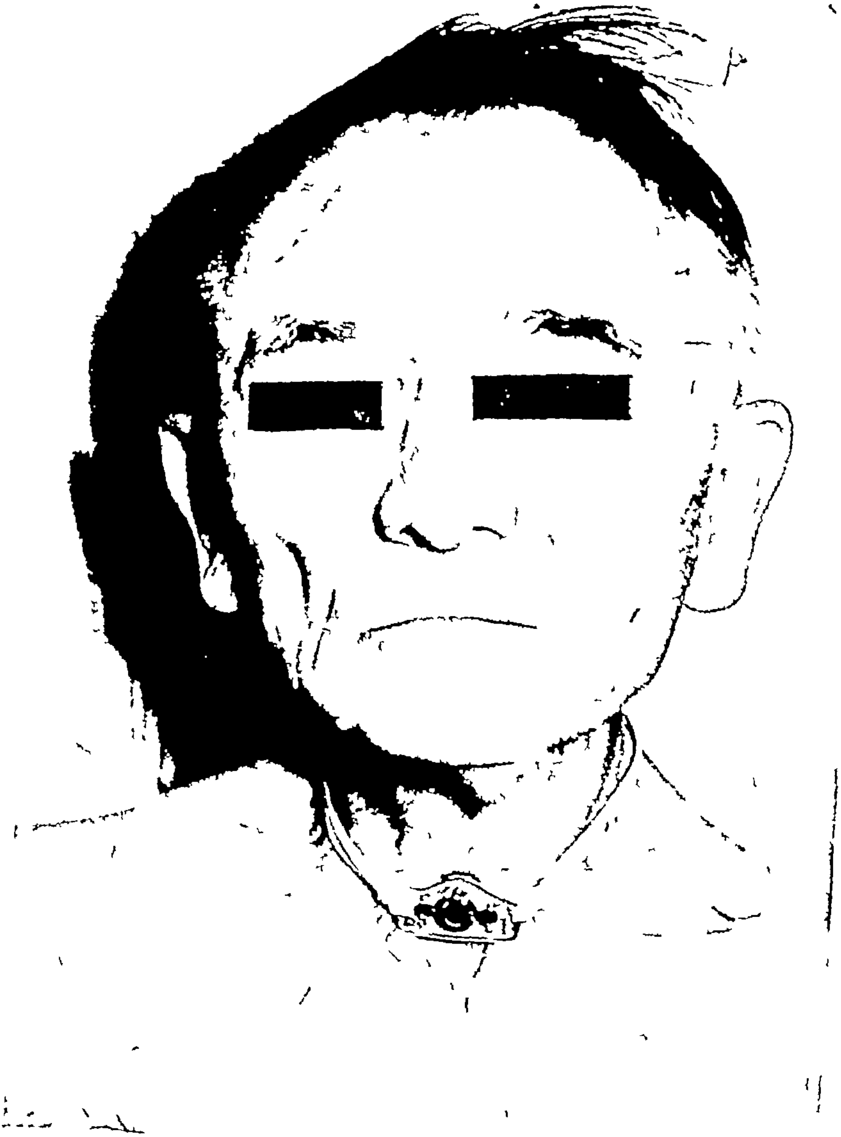

Fig 2 Photograph showing appearance of neck 22 years later with the tracheotomy tube *in situ*

The histopathologic report was that of medullary squamous cell carcinoma Grade IV with extensive anaplasia and nuclear degeneration There were marked poikilocytosis and anisocytosis with hydropic degeneration of protoplasm The characteristic feature above all others was a very active lymphoid reaction (see Fig 1)

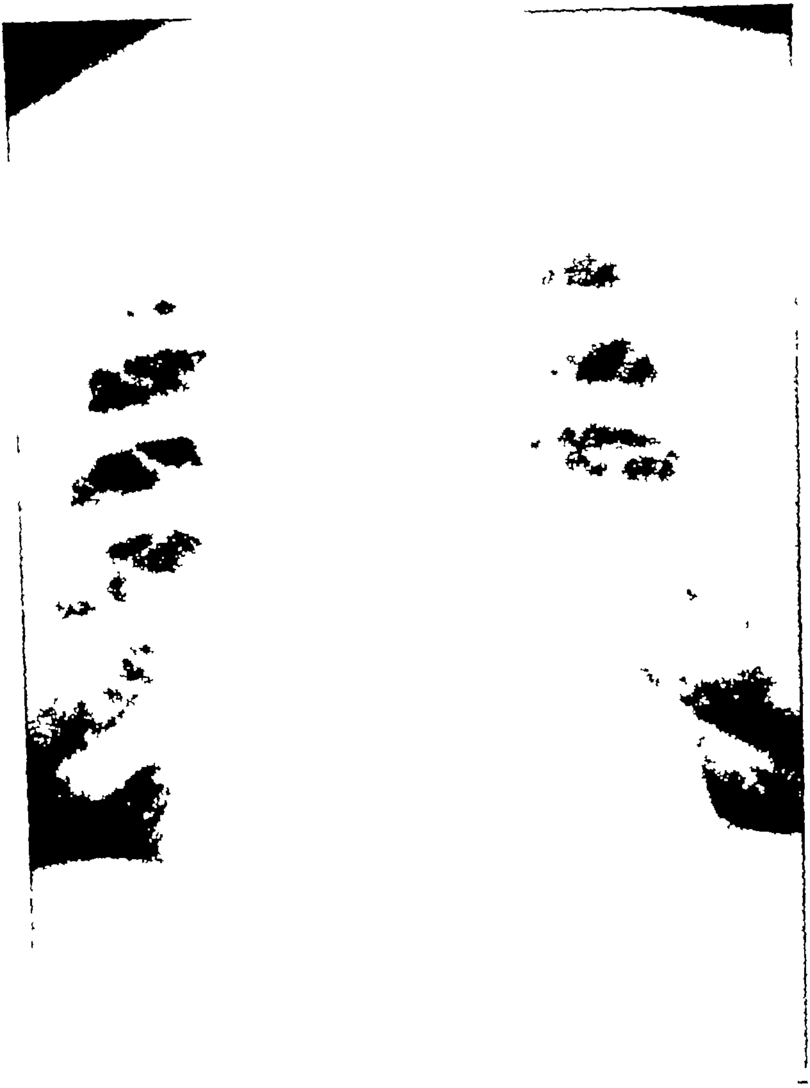

Fig 5 Posteroanterior roentgenogram of the chest reveals slight generalized pulmonary edema with some prominence of the bronchovascular markings

was in good general condition There were no palpable lymph nodes of the neck and no hoarseness Indirect laryngoscopic examination showed a normally functioning larynx There was no evidence of any carcinoma and the vocal cords were freely movable

October 30 1944 The patient has gained an additional three pounds

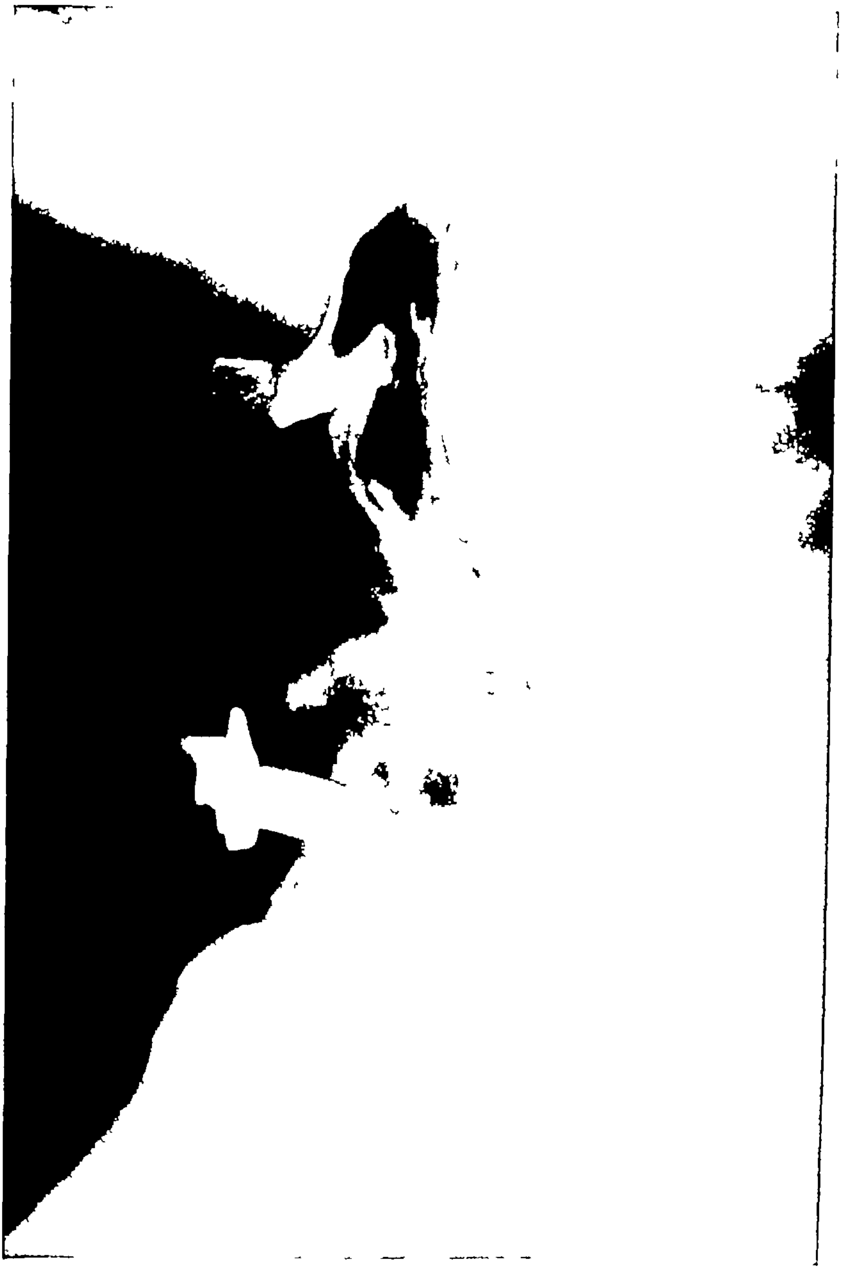

Fig 4 Lateral roentgenogram of the neck with soft tissue exposure and barium swallow shows no abnormality of the esophagus

# A TECHNIQUE OF TYMPANOPLASTY (TYMPANOMALLEOLAR STAPEDIOPEXY) *

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In a recent article, "Technique of Tympanoplasty", published in the *Archives of Otolaryngology,* the author reported on two cases of tympanomalleolar stapediopexy. It was noted that where possible, if the head of the malleus was preserved and rotated in such a manner that it were allowed to come in contact with the capitulum of the stapes, it not only served as a sound conducting structure, but also produced a tenting effect on the drum or new graft, thus preserving a greater vibratory capacity of the drum.

Since the vibratory capacity of the tympanic membrane, or new graft, plays the major role in the transformation of sound pressure from drum to oval window,[1-17] it is mandatory to maintain as much vibratory area as possible in the tympanoplasty procedure. Much work has been recorded in the European literature showing attempts to improve vibrating surface of new grafts. In a few cases Wullstein attempted to line the hypotympanum and tubotympanum with ocular conjunctiva or amniotic membrane. This would seem to make for a more complicated procedure in an already complex operation. House has described the use of vinyl prostheses placed in the hypotympanum and extending through the Eustachian tube.

In my own series of 100 cases of tympanoplasty, surveyed as of July, 1956, all Type III tympanoplasties or tympano stapediopexies were carried out in the conventional manner, namely:

*1.* Tympano atticotomy and removal of diseased tissue from the antrum and removal of surgical bridge.

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weighing 144 pounds, and he continued to feel well There was no evidence of cervical lymph adenopathy Laryngoscopic examination was negative for any pathology

July 11 1945 Weight 144 pounds Laryngoscopic examination negative Neck normal

February 21 1948 Weight 148 pounds General condition excellent Larynx and neck normal

October 26, 1956 Patient reported to the office with a history of recent spells of difficult breathing There were no other complaints Indirect laryngoscopic examination revealed abductor paralysis of both vocal cords

On October 27, 1956, he was re-admitted to Harper Hospital for a tracheotomy Examination at this time revealed a well developed and well preserved elderly white male who had obvious laryngeal stridor and hoarseness His distress was not acute and the stridor was more marked with expiration The general physical examination was negative, and the laboratory data were all within normal limits There was no evident induration of the structures of the neck and no enlargement of the cervical lymph nodes

On October 28, 1956, direct laryngoscopy and tracheotomy were performed The larynx was negative for any swelling, ulceration or tumor masses There was bilateral abductor paralysis of the vocal cords of indeterminate cause

The patient was discharged to his home on November 5 1956

On February 1, 1957 patient was re-examined There was a normal appearance of the neck externally except that a tracheotomy tube was *in situ* (see Fig 2) Laminagraphic examination of the neck was made in the coronal plane (see Fig 3), which revealed the following findings A tracheotomy tube was in place but did not interfere with visualization of the glottic area There was a marked distortion of the glottic folds on the two sides, particularly on the left, but with the patient phonating the letter 'e a fairly good apposition of the vocal cords was obtained and the Morgagni space appeared fairly normal in contour Lateral roentgenograms of the neck with soft tissue exposure likewise showed the tracheotomy tube in place but no other findings Barium swallow demonstrated no definite esophageal abnormality (see Fig 4) Posteroanterior roentgenograms of the chest disclosed slight generalized pulmonary emphysema with consequent prominence of bronchovascular markings throughout the lung fields There was an old pleural reaction in the left costophrenic sulcus region but no active lung disease No parenchymal or pleural metastases were seen The ribs, insofar as visualized appeared intact (see Fig 5)

## SUMMARY

A case of advanced medullary squamous cell carcinoma of both vocal cords, taken from a series of 15 cases published formerly, is reported briefly The patient was treated with supervoltage Roentgen therapy and has now survived for a period of 22 years

Harper Hospital

has its own natural simple stratified squamous inner lining, and good results are obtained in the majority of cases, again where there is only a marginal rim of drum membrane present and it must be preserved for attachment of the new graft to the denuded drum remnant. It not only serves as support for the new drum but also provides excellent blood supply for its preservation Where the ear is dry and the mucosal lining of the tympanic cavity is thin and atrophic, good results will be obtained with tympano stapediopexy but in a smaller percentage of cases, because in an effort to contact the graft to the stapes adhesions and a lowered vibratory area results If the mucosal lining of the cavum tympanum is hyperplastic and cystic it must be stripped away, along with carious deposits in the hypotympanum and tubotympanum, and the problem of maintaining a mucosal-lined cavity with a vibrating new drum contacting the stapes becomes increasingly difficult If one errs in preserving the mucosa, he will many times end up with a persistently discharging ear, a slight or no hearing gain and a dissatisfied patient

In the review of post operative results, it was noted that the larger the drum defect replaced with free graft contacting the stapes, even though all other ideal conditions in the tympanic cavity prevailed for optimum results, the less consistent were good hearing results Many times, the three-week audiogram would show a good hearing gain, well above the 30 db level, only to be followed by a gradual recession of the pure tone curve at or below the level of adequacy (30 db level) This loss is unquestionably due to fibrosis of the raw inner surface of the new graft to the medial wall of the tympanum, resulting in reduction of vibratory capacity, thus lowering the sound conduction ratio It becomes essential then to preserve as much vibratory area as possible, and to do this one should attempt to elevate the flap from the tympanic wall rather than merely to adhere it to the bony prominence of the cochlear promontory Realizing that the promontory is necessary many times as a source of blood supply for the new graft, elevation of the graft is still not only a prerequisite but also a definite advantage as far as sound conduction ratio is concerned

*2* Gross and microscopic examination of the ossicular chain for cholesteatoma or disruption of ossicular chain If the otologist is assured of absence of intra-tympanic pathology, such as is many times the case in so-called primary cholesteatoma of pars flaccida, and if the stapes is mobile along with intact ossicular chain, the pedicle graft is used, the edges of the perforation are approximated and the patient is assured of reasonably good hearing at least above the 30 db level Some observers have stated that many times the hearing will recede in these cases due to

*a* eventual dislocation of the incus from the head of the stapes

*b* adhesions from the pedicle hampering the movement of the ossicular chain

I believe that dislocation of the incus is an operative hazard, and secondly, adhesions may be avoided if one preserves a high dome on the facial ridge, and if one preserves the anterior and posterior spines

*3* If there is bony ankylosis, or a dehiscence in the narrow portion of the long process of the incus constituting a break in the ossicular chain, one then elects to do a tympano stapediopexy The anterior and posterior spines are removed, and the facial ridge is lowered as far as possible, almost to the facial nerve itself The tympanic membrane is mobilized posteriorly, escharred on its inner surface and tucked into the niche of the oval window contacting the head of the stapes Many times the capitulum projects to the level of the lowered facial ridge, and contact is no problem

Good results are obtained with tympano stapediopexy in those ears with perforation of the pars flaccida and primary cholesteatoma, because as a rule the mucosal lining of the cavum tympanum is intact and the hypotympanum and tubotympanum are not involved Likewise, good results are obtained where there are small marginal perforations of the pars tensa, providing one can preserve the mucosal lining of the tympanic cavity and the round window is demonstrated to be patent In both of these cases the tympanic membrane chain, assuming mobile stapes and normal round window membrane with patent niches are present

2 Tympano malleolar stapediopexy, or stapes to malleus to drum procedures, are employed where large marginal drum defects (30 per cent or more) are present, and stripping of cystic hyperplastic mucosa from the tympanum, hypotympanum, and tubotympanum is necessary

3 It is felt that preservation of the malleus rotated and applied to the head of the stapes produces a tenting effect and better vibratory capacity of a new drum more free of adhesions to the medial tympanic wall surrounding the stapes

4 The observation is made of good hearing improvement to the satisfactory level in a secondary fenestration of a radical cavity in which there was no gross evidence of a mucosa-lined cavity from the tubotympanum to the patent round window, thus indicating that possibly in some cases only an air bubble over a functioning round window membrane is necessary for adequate intra-labyrinthine phase interval

5 It is, therefore, theorized that in those patients with atrophic or absent mucosal lining in the vicinity of the round window area, if there is satisfactory tenting of a new graft, produced by the head of the malleus, assuming a functioning round window membrane exists, it is possible to achieve a satisfactory hearing gain, even though there is no gross evidence of mucosally lined cavity demonstrated by mobility of the new drum.

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## AMERICAN BOARD OF OTOLARYNGOLOGY

The American Board of Otolaryngology will conduct only one examination in 1958, and this will be October 6-9, 1958, in Chicago, Illinois, at the Palmer House

For further information address Dr Dean M Lierle, Secy-Treas , University Hospital, Iowa City, Iowa

In the last 70 tympanoplasties, operated on since July, 1956, I, therefore, have concentrated on preserving the head of the malleus where possible, in all cases in which extensive intratympanic surgery was performed, and large free graft was employed, rotating it over the head of the moveable stapes and attaching the free graft to the denuded drum remnant, the head of the malleus and the facial ridge posteriorly This creates a tenting support of the new drum and provides a greater vibrating surface at the oval window, as well as a shielding of the round window Applying this principle to those cases in which it was necessary to employ radical removal of diseased hyperplastic mucosa in the entire tympanic cavity and obtaining a few good hearing improvements, I then employed the procedure in a few patients with pars flaccida lesions with uniformly good results At the present time, where possible, the head of the malleus is preserved in all cases with large marginal defects and extensive disease of the tympanic cavity and where the stapes is deeply set, and hearing is in my opinion better than in stapes to drum procedures, due most likely to increased vibratory capacity

It was noted that in one patient in whom a secondary fenestration procedure was performed on a dry radical mastoid cavity in which there was no gross evidence of mucosa-lined cavum tympanum, the patient received an excellent hearing gain to the practical level This indicated that a mucosa-lined cavity extending from the round window to the Eustachian tube may not be necessary in all cases, but merely an air bubble over the round window would suffice for preservation of intra-labyrinthine phase relationship, providing the round window were patent and the stapes mobile This would be especially true providing the mucosa were atrophic or absent

## CONCLUSIONS

*1* Tympano stapediopexy, or stapes to drum procedures, are employed where the membranous lining of the cavum tympanum is intact and the simple squamous lining of the tympanic membrane is normal, such as in a perforation of pars flaccida, cholesteatoma and ankylosed or broken ossicular the reconstructive operation in one stage Multiple operations tend to create more fibrosis and adhesion formation

Five types of tympanoplasty (Wullstein[2]) have been advised to accommodate these various pathological changes

*Type I* Plastic closure of an eardrum perforation

*Type II* Preservation of the ossicular chain with large grafts covering the perforated drum and the bridge and/or ossicles

*Type III* Removal of the malleus, incus, and bridge, and the placing of a graft onto the drum remnants and head of the stapes

*Type IV* Removal of remnant of ossicles and bridge in cases without a stapes with a graft applied to the promontory or into the oval window and sealing off the hypotympanum, round window and Eustachian tube from the external ear

*Type V* Same as Type IV, with the addition of fenestration into the horizontal semicircular canal

A comparison has been obtained between 76 tympanoplasties performed in the first ten months of 1957, with 75 conservative or modified radical mastoidectomies performed in previous years, as to results achieved Against these two groups we have also tabulated a group of 50 radical mastoidectomies

In demonstrating the results obtained in the tympanoplasties, one must consider, first of all, that these are the earliest cases attempted in this type of surgery, and second, these cases are so recent that final hearing results may be somewhat better than we demonstrate at present, furthermore, these cases are not selected, but rather represent consecutive cases that presented themselves and were operated upon, using various ones of the five types of tympanoplastic procedures described by Wullstein [2]

The method of charting the comparisons is as follows The hearing before surgery was averaged for the frequencies of 500, 1000, and 2000, and plotted on a vertical line Gains in

# RESULTS IN TYMPANOPLASTY

## A Comparative Study of 76 Tympanoplasties, Contrasted with Modified Radical, and Radical Mastoidectomies *†

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Detroit, Mich

Tympanoplasty may be defined as the combination of surgery for eradication of chronic ear inflammation and surgical reconstruction of the sound conducting and sound protecting mechanism Frenckner[1] reported recently "Tympanoplasty is now embraced with greater interest in a number of different clinics in Europe In my opinion, this would seem to have become one of the broadest and most important fields of operation within otology during the recent decades In the United States, on the other hand, this operation is viewed with considerably more skepticism, and has not yet aroused the proper interest" My comment here would be, that many American otologists are now working in this field, and it is hoped that before long we will contribute to the progress of this concept, pioneered by European otologists

From what we have learned in tympanoplasty, it is apparent that early operation of chronic ear inflammation is advisable, both from a functional and also from the microsurgical and anatomical point of view When it is obvious that an inflammatory disease in the middle ear is irreversible by conservative measures, and will progress with functional deterioration, it is imperative that surgery be performed, even though an ideal result can not be promised The earlier that this is done, the less destructive will be the pathological changes in the epitympanum, ossicular chain, drumhead, Eustachian tube, hypotympanum, annular ligament, and round window niche and membrane Every attempt should be made to perform

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*Read at the meeting of the Middle Section American Laryngological, Rhinological and Otological Society Chicago, Ill Jan 13 1958

†Department of Otolaryngology Wayne State University

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taneously with a false drum adherent to the promontory and protecting the round window Toward the end of this series were recorded a group with profound losses in hearing, due to serous labyrinthitis complicating fistulas in the horizontal canal These cases submitted to radical mastoidectomy because of labyrinthine complications

A group of 75 consecutive conservative or modified radical mastoidectomies were then reviewed, (see Figs 3, 4, 5, 9)

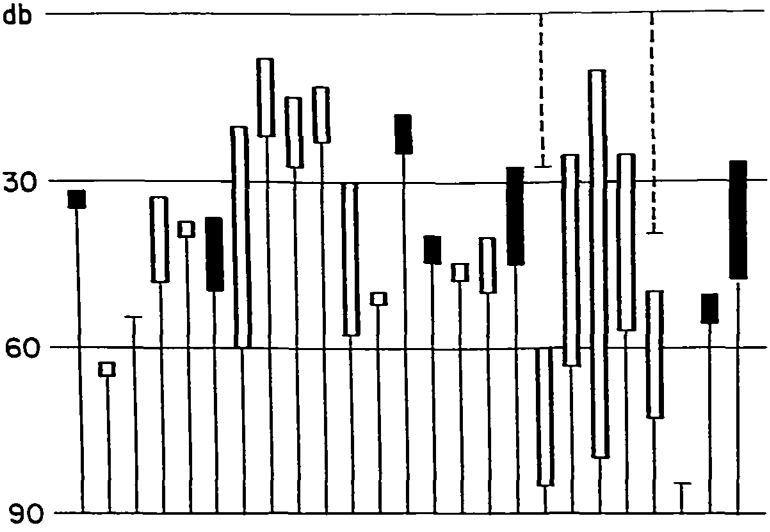

Fig 2 Radical Mastoidectomy

Many of these cases were undoubtedly candidates for radical exenteration, but because active pathology appeared to be confined to the attic and/or antrum, the middle ear was often not disturbed, hoping that some hearing would be restored In almost every case the bridge was removed In all cases the ossicles or remnants of ossicles were not removed The drum was not elevated or disturbed in any way When feasible a portion of the membranous posterior canal wall was left attached to the drum and swung on a pedicle to cover the ossicles Failure to gain healing if coupled with suppuration, was followed by radical revision In 17 of the 75 cases, hear-

hearing are indicated on the vertical lines by the shaded bars, and losses by open bars No change is indicated by a short horizontal line Bone conduction losses are indicated by the dotted lines dropped from the top of the charts A bar connecting two vertical columns below the base indicates the two ears in one patient If the conductive loss is greater than 30 db for the main area of speech, the result is regarded as unsatisfactory, even though the operation produced a definite increase in the hearing

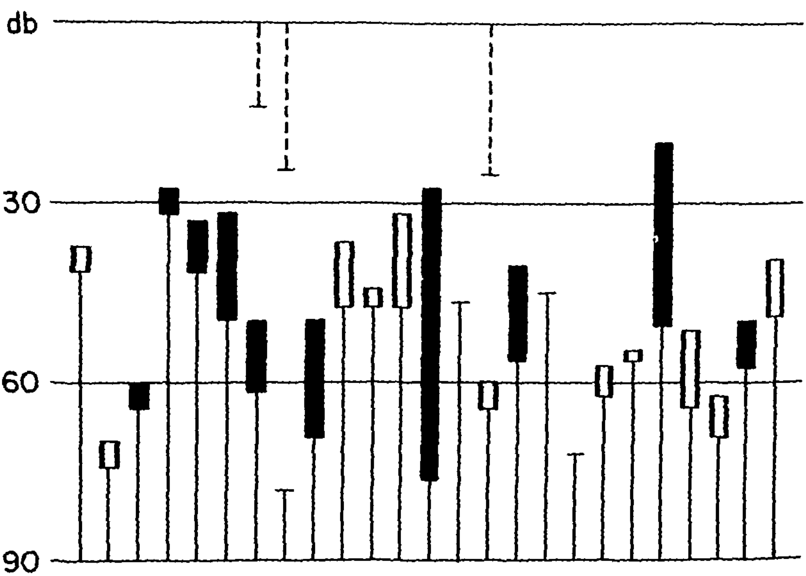

Fig 1 Radical Mastoidectomy

Before considering the conservative radical mastoidectomy group, we shall review the results obtained in the radical mastoidectomies with respect to hearing gain or loss This will give us some sort of base line to judge the effectiveness of the conservative radical ear surgery group In the group of 50 radical mastoidectomies tabulated (see Figs 1, 2), a total of 17 showed some gain in hearing, but only six improved over the 30 db level A total of 27 sustained further loss in hearing, and six were unchanged Two cases with a marked gain in hearing, surpassing the 30 db level, had healed sponis attributed to a perforation in the graft and to the formation of adhesions in the tympanum

Preservation of the ossicular chain with large grafts covering the perforated drum and the bridge and/or ossicles—Type II tympanoplasty (see Figs 6, 9) was performed in 23 cases In five cases gains to above the 30 db line were obtained In seven cases further hearing gains above this line were recorded In four cases some hearing loss occurred, but remained at or above the 30 db line In seven the 30 db line was not reached Seventy per cent of these cases had hearing above 30 db, and of these 35 per cent had hearing above a 15 db level Wullstein[2] considers the 15 db line a satisfactory level in Types II and III tympanoplasty These results compare favorably with those reported in this same manner by Wullstein[4] The results are surprisingly similar to those obtained with the modified radical mastoidectomy in 75 cases (see Fig 9) Jongkees[3] reoperated nine Type II tympanoplasties and attributed failures originally to the following Leaving ossicles with small defects, hoping that they would heal,

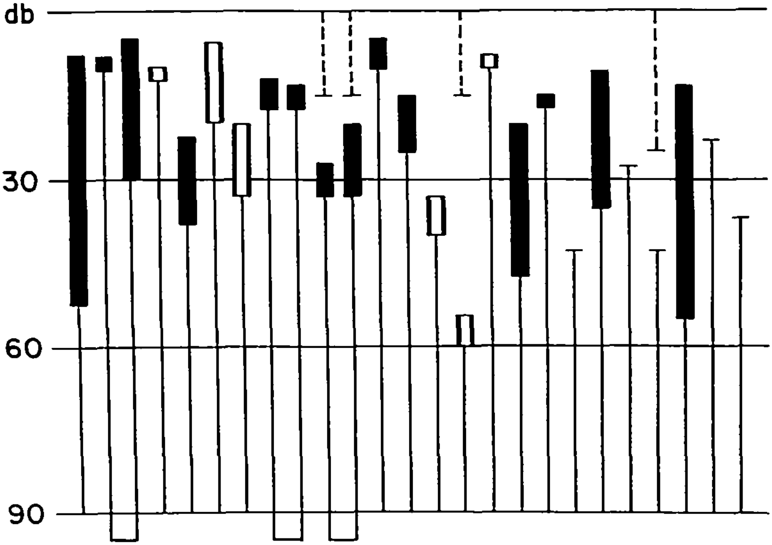

Fig 4 Modified Radical Mastoidectomy

ing was brought up to or surpassed the 30 db level In 32 cases, preoperative hearing losses of less than 30 db was maintained above that level Thus a total of 49 cases (65 per cent) benefited audiologically by conservative radical mastoidectomy as contrasted with only 12 per cent in the radical group Only five cases with preoperative hearing loss of less than 30 db dropped below this level

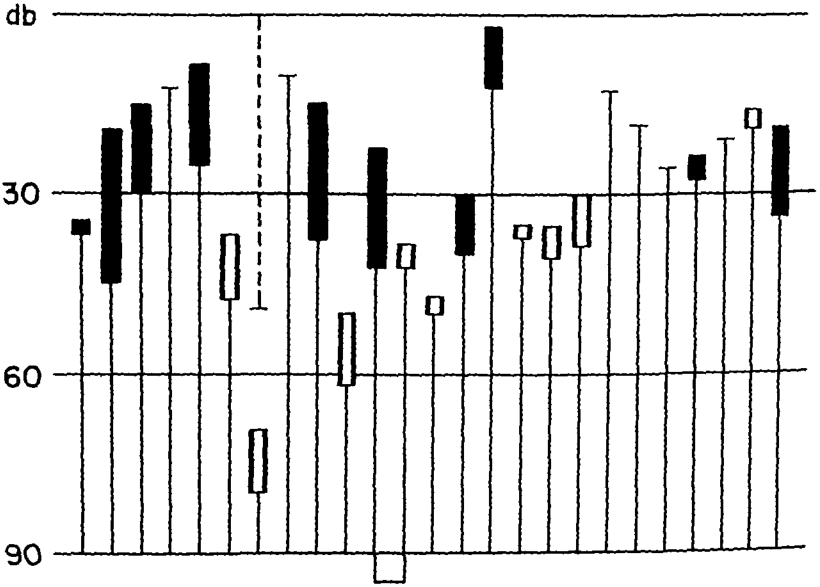

Fig 3 Modified Radical Mastoidectomy

In the first ten months of 1957 a total of 76 tympanoplasties were performed and their results compiled, even though many of them have not entirely healed It must be remembered that a survey of this type does not give an accurate picture of the benefits of this surgery For example, a cholesteatoma uniting disrupted ossicles may be responsible for relatively good hearing which drops considerably with the sole removal of the cholesteatoma Zollner[3] states that the starting point of rehabilitation should be reckoned at the lower level

Plastic closure of an eardrum perforation—Type I tympanoplasty (see Fig 6) was attempted in only four cases, with satisfactory results in three The failure in the fourth case

The relatively poor results in Type III, as contrasted to Type II, can be explained by the more extensive destruction of middle ear structures, and particularly the mucosal lining Destruction of mucosa by the inflammatory disease process, combined with a more complete removal of the bridge, predisposes to more extensive postoperative adhesion formation, particularly about the stapes, also, often very little, if any, is left of the eardrum, and the manubrium of the malleus is

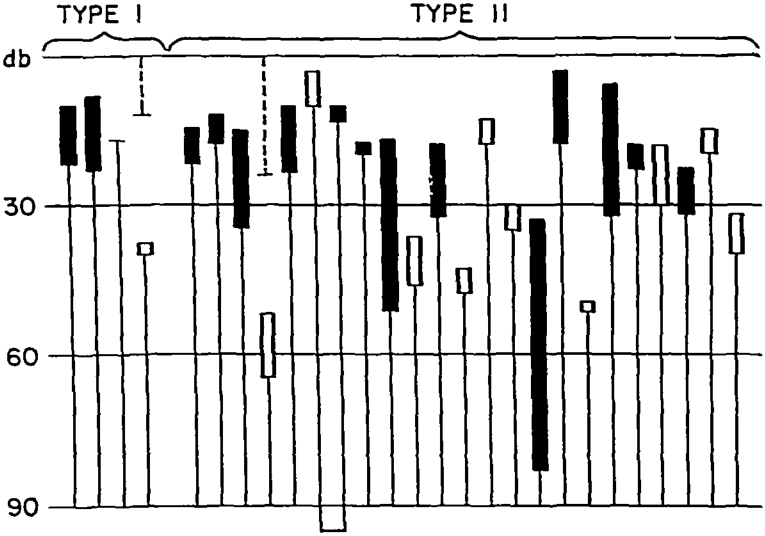

Fig 6 Tympanoplasty Types I and II

removed, so that the newly created eardrum is audiologically less effective than the normal drumhead Among nine failures reported by Jongkees[5] in Type III, the following factors were found responsible The arch of the stapes had been broken, residual inflammation had continued to destroy the originally intact stapes, too stiff or calcified stapedius tendon which prevented vibration of the stapes, non-adherence of the drum or graft to the head of the stapes, and adhesion of the drum to the promontory, due to too thick a graft, or insufficient post-operative inflation of the Eustachian tube

When the stapes is destroyed the latter cannot be used for its columellar (sound transmission) effect One might overlooking a disrupted ossicle, attempting to bring mutilated ossicles into contact with one another, insufficient removal of disease from middle ear or attic, covering active pathology with a skin graft, and granulation or cholesteatoma had reformed, and inadvertently overlooking a dislocation of the incus At reoperation the middle ear was cleaned, the incus and head of the malleus removed and the drum placed on the head of the stapes

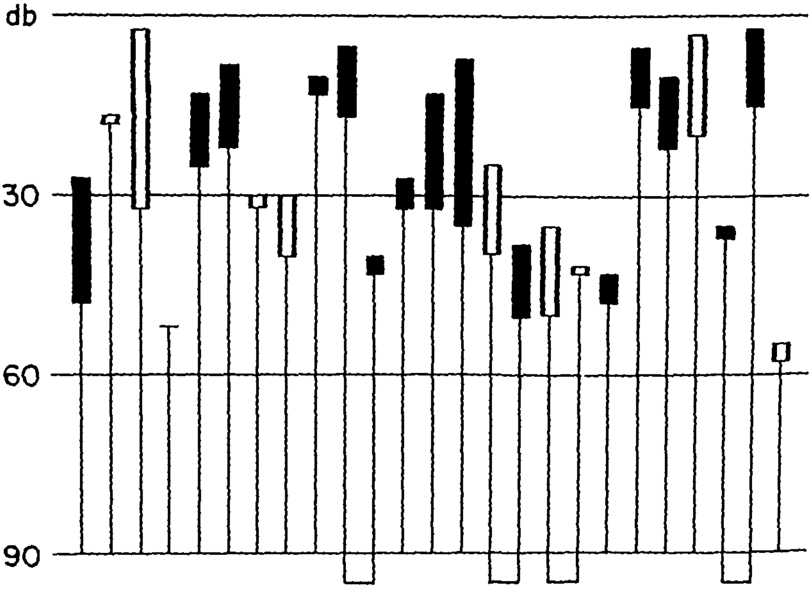

Fig 5 Modified Radical Mastoidectomy

Removal of the malleus and incus and the placing of a graft onto the drum remnants and head of the stapes—Type III tympanoplasty (see Figs 7, 9) was performed in 26 cases Hearing was improved in 20 cases, decreased in four cases, and remained unchanged in two cases In 12 cases the 30 db line was reached, and in five of these the 15 db line was reached In three cases hearing was maintained above the 30 db level, and one remained above 15 db The results reported by Wullstein[4] are better, in that 17 per cent of his patients reached the 15-30 db level This gap could probably be narrowed in time by improvement in skill and judgment panoplasty This has been attributed to the relatively thick, relaxed graft which seals off the small tympanum, offering excessive sound protection to the round window while the stapes footplate remains free Failures in 11 cases of Type IV tympanoplasty were revised by Jongkees[5] and were attributed to Closure of the oval window by tough connective tissue, the skin graft had not healed onto the oval window membrane or stapes footplate, a mass of tissue had formed

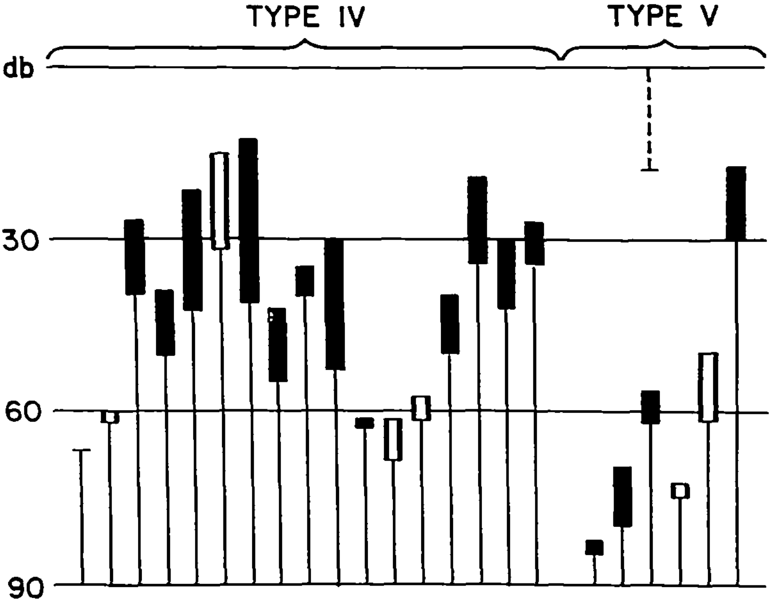

Fig 8 Tympanoplasty Types IV and V

in between the flap and the membrane of the oval window, or that the flap was too firmly fixed to the promontory

When the stapes footplate is fixed by new bone formation or dense adhesions so that it cannot be mobilized, one must consider then a fenestration into the horizontal semicircular canal with a graft again placed to seal off the round window, hypotympanum and Eustachian tube from the external ear—Type V tympanoplasty (see Fig 8) Six cases were attempted in this fashion The first five were old radical be able to use the transposition of a portion of the malleus or the incus to obtain a substitution columellar effect, (Miodonski,[6] Hall and Rytzner[7]), but often that is not possible, so that the choice is to create sound protection for the round window with a graft applied to the promontory, and if necessary into the oval window niche with sealing off of the hypotympanum

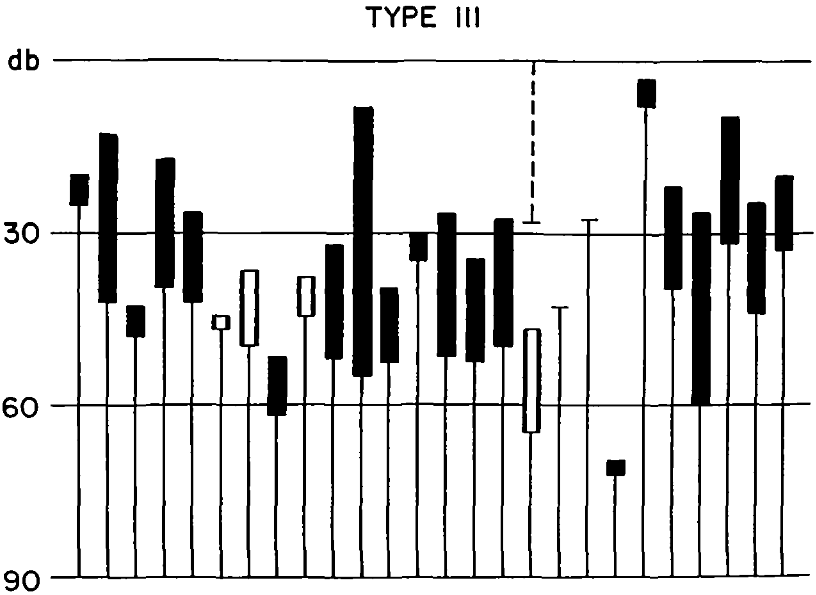

Fig 7 Tympanoplasty Type III

If the stapes footplate is mobile or can be mobilized, it is left open to the radical cavity—Type IV tympanoplasty (see Figs 8, 9) Kley[8] states that post-operative hearing with the stapes footplate alone, or with only a membranous occlusion of the fenestra ovalis is not worse than with a preserved stapes or formation of an artificial columella Seventeen cases were performed in this manner Seven reached the 30 db level of hearing, another four obtained a less satisfactory gain in hearing, one dropped below the 30 db line, and four obtained no benefit

Wulstein[4] and also Richtner[9] have reported a large number of theoretically excessively good results after Type IV tymof otology  Type I tympanoplasty has its place in closure of benign and dry perforations of the drum  Type II is not much different from the old concepts of conservative radical mastoid surgery, but with the refinements of microsurgery, combined with experience and good judgment, we can eliminate some of the failures encountered with the conservative operation  Type III is a new concept of corrective surgery with restoration of function in a large percentage of cases which previously had been subjected to radical mastoidectomy  The surgery in Type IV is a distinct and marked improvement in the treatment of advanced middle ear disease and holds much promise for the future  The old alternative was the radical mastoidectomy, and it has been demonstrated that hearing results with that procedure are markedly poor  Type V in properly selected cases, and they are infrequent, should often result in gratifying improvements due to the achievement of sound protection for the round window and the creation of a new window open to the external ear

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1229 David Whitney Building

mastoidectomy cavities with marked hearing loss in the opposite ear The results obtained were all unsatisfactory because of one or more of the following factors Mucosal grafts were placed across the hypotympanum to the Eustachian tube and may not have been effective, excessive fibrosis was present in both windows and probably reformed in the round window, three of the grafts perforated presumably because of poor vascularity, and in two the membranous labyrinth appeared pathological, although preoperative bone conduction tests indicated good nerve function Miodonski[9] reports three cases of Type V tympanoplasty with a markedly reduced lumen in the semicircular canal and ampulla (phthisis labyrinthi, Zange) Preoperative vestibular reactions were weak in his cases In the last case charted, one which had not been operated before, a satisfactory result was obtained

| | | ABOVE 15 db | 15-30 db | BELOW 30 db |
|---|---|---|---|---|
| TYPE II | 23 cases | 35 % | 35 % | 30 % |
| WULLSTEIN | | 30 | 40 | 30 |
| TYPE III | 26 cases | 19 | 39 | 42 |
| WULLSTEIN | | 15 | 60 | 25 |
| TYPE IV | 17 cases | 6 | 36 | 58 |
| WULLSTEIN | | 19 | 50 | 31 |
| MODIFIED RADICAL | 75 cases | 37 | 28 | 35 |

Fig 9 Summary of results obtained in Types II III and IV tympanoplasty and comparison of results reported by Wullstein in 350 cases also results obtained in 75 modified radical mastoidectomies

The surgery of tympanoplasty offers much to the future a surgical method for achieving this result, which they called "tympanoplasty" Since the recent publication of articles by these physicians in English and American journals, interest in tympanoplasty has been great in this country Plastic procedures on the middle ear for closure of perforations and improvement of hearing have been developed during this same period, principally by American otologists, including Juers,[5] House,[6] and Wright, Guilford and Draper[7] These techniques are most interesting, but are not within the scope of this paper

Although my experience with tympanoplasty is still limited, it was thought that some information might be gained from a brief review of my cases Between March 21, 1957, and November 1, 1957, 16 tympanoplasties were done by me at Ochsner Foundation Hospital on patients ranging in age from four to 45 years In the ensuing paragraphs selection of cases, technique, and results of tympanoplasty will be discussed in the light of this experience

## SELECTION OF PATIENTS

Tympanoplasty can be performed on any patient with chronic otitis media and mastoiditis, provided cochlear function is adequate to warrant this more time-consuming and meticulous procedure I prefer myringoplasty in patients with traumatic or long healed and dry central perforations that have proved resistant to more conservative attempts at closure

Preoperative pure tone air and bone audiometry, and speech audiometry, are essential Use of the acoustic probe, as advocated by Zollner[1,2] seems unnecessary to me, because the ossicular chain and window function will be inspected at operation Its value is even questionable because of sound conduction by the diseased products present

Preoperative determination of the predominate pathogenic organism and appropriate antibiotic, followed by a period of local and systemic treatment, is desirable but not essential Disease of the paranasal sinuses and nasopharynx should be

# EARLY EXPERIENCE WITH TYMPANOPLASTY (WULLSTEIN TECHNIQUE) [*][†]

MILES L LEWIS, M D ,

New Orleans, La

Until recently it has been customary to classify chronic otitis media and mastoiditis in two general categories surgical and non-surgical The basis of this division depended upon the likelihood of extension of the pathologic process to the brain, labyrinth or facial nerve, in the opinion of the classifier, and upon the presence or absence of cholesteatoma This classification was a good, but not infallible guide, as cholesteatoma and intracranial complications can also occur in "non-surgical ears"

Numerous "modified" radical operations have been devised in an attempt to conserve or improve hearing in these patients Such procedures have often resulted in satisfactory eradication of the disease, even though some had to be converted later to radical operations, but they have been rather disappointing from the standpoint of improvement of hearing Thus the goal in the surgical treatment of chronic otitis media and mastoiditis is two-fold primarily, eradication of the disease, and second, satisfactory postoperative hearing

For many years otologists have been astounded by the occasional patient with healed chronic otitis media, or radical mastoid cavity, whose hearing was excellent On inspection of these patients it was noted that a membrane had formed, enclosing the orifice of the Eustachian tube and the round window niche, and that occasionally this membrane was adherent to the stapes Zollner[1, 2] and Wullstein,[3, 4] working in different universities in Germany, made these observations and began working, in the years after World War II, to devise

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[*] Read at the meeting of the Southern Section American Laryngological, Rhinological and Otological Society Inc Jan 25-26 1958 Memphis Tenn

[†] From the Department of Otorhinolaryngology Ochsner Clinic New Orleans

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### TECHNIQUE

The technique of tympanoplasty is not stereotyped, it must be adapted to the pathologic alterations present Unless intracranial extension is present or imminent, the operation is done in one stage The basic principles are simple, and have been lucidly presented by Wullstein[3,4] The principal factors in sound transmission to the inner ear are sound pressure transformation from the tympanic membrane to the labyrinth, and sound protection of the round window In Types I and II the ossicular chain is intact, and the attic is preserved, thus, both of these factors are present In Type III sound protection of the round window and partial sound pressure transformation *(through the "collumella effect" of the stapes)* are present In Types IV and V sound protection of the round window is the only factor present

If an air-containing, mucosal-lined, middle-ear space, enclosing anteriorly a patent Eustachian tube and posteriorly a freely moveable round window membrane, can be developed and maintained, useful hearing will result, provided the stapes footplate is freely moveable and cochlear function is adequate The following technique was employed in the cases in this series

A full thickness skin graft is taken, half from the posterior surface of the auricle and half from the postauricular region, as advocated by Wullstein[3,4] The margins are undermined, and the defect is closed with mattress sutures An endaural incision is made, and the posterosuperior membranous canal is removed by an incision to one millimeter lateral to the annulus The mastoid antrum is exposed by removal of bone with cutting burrs posteriorly, beginning two millimeters lateral to the notch of Rivinus A flat low bridge is formed, and all diseased mastoid cells are exenterated, care being taken to form as small a bowl as possible

Attention is then directed to the middle ear and attic The remainder of the operation is done through the operating microscope All vital areas must be inspected ("controlled") with as little disturbance to the remaining tympanic membrane and ossicles as possible This includes the attic, ossicles, round window niche, mesotympanum, hypotympanum, and orifice of the Eustachian tube This may be possible through a large central perforation Often it is necessary to drill the control windows of Wullstein,[3 4] to enlarge the attic by turning down Shrapnell's membrane and removing bone from below upward, or perhaps to cut the bridge anteriorly to remove the matrix of the cholesteatoma from the anterior extent of the attic It is advisable to check the lenticular process of the incus and its articulation with the stapes early, as this is the most vulnerable portion of the ossicular chain, and if it is not intact, the procedure can be greatly shortened by removal of the bridge All cholesteatoma and diseased mucosa must be removed from the attic, mesotympanum, hypotympanum, stapes or oval window, round window niche, and orifice of the Eustachian tube This is accomplished by use of small scissors, curettes, cup forceps and suction Mobility of the footplate of the stapes is determined by presence of the "change pressure" (stapedius reflex) sign As much mucosa as possible is saved over the area that is to form the new middle ear The areas that are to form the bed for the graft are prepared down to subepithelial tissue or to bone After the annulus fibrosa, and as much of the tympanic membrane as possible have been saved, the entire area has been carefully inspected for residual disease, and bleeding has been controlled, it is time to place the graft The graft should be carefully prepared beforehand and thinned of all subcutaneous tissue so that it is soft and pliable Small pledgets of Gelfoam® soaked in penicillin solution are then placed over the area that is to form the new middle ear, extending from the orifice of the Eustachian tube into the round window niche The graft is then laid in position, adjusted, and cut to fit Larger pieces of Gelfoam® are placed over the graft, and the remaining cavity is packed with vasoline gauze strips, and a basket filled with small sponge squares

Postoperatively, all packing is removed after six days, the Gelfoam® over the graft is removed on the tenth day, and the Eustachian tube is carefully inflated on the tenth to four-

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teenth day The tube is inflated at each postoperative visit thereafter, and the patient is instructed to inflate his ear carefully by the Valsalva maneuver daily

## TECHNICAL PROBLEMS

In my limited experience with this procedure several minor technical problems have become evident The graft should be wide My early tendency to make the graft too narrow, and thereby produce less "pinning back" effect on the auricle, was an unwarranted fear, as in several months the auricle will assume its original position A small new middle ear is desirable, as the smaller the free portion of the graft, the less likely it is for perforation to occur A wide gap between the anterior wall of the external auditory canal and the facial ridge is desirable, the anterior edge of the graft should be bevelled, and should not extend too far laterally on the anterior wall of the external auditory canal There should be no folds or overlapping of the graft, and the stapes footplate should be left uncovered by the graft in Type IV procedures The bowl must extend to the level of the floor of the external auditory canal, and the facial ridge should be quite flat, to facilitate the placing of the graft and to permit easier postoperative care

Experience in dissection and use of the drill through the operating microscope is rapidly gained, and presents no problem Meticulous attention to detail in cleansing the stapes and round window niche is essential to a good result

It has been said "better a good Type III or IV than a poor Type I or II" The less experienced the surgeon in this work the truer is this expression The primary concern is complete removal of the disease, and plastic reconstruction of the sound-conducting apparatus will not be successful if this is not done

## RESULTS

Of the 16 tympanoplasties, two were Type I, nine Type III, and five Type IV Twelve of the 16 patients have intact, inflatable middle ears Three have had perforations in the graft, one of which was closed by cauterization and patching with regain of hearing Two new middle ears have been closed by adhesions Of the two patients who had Type I procedures, one has essentially normal hearing and the other a large perforation in the graft with no gain in hearing One of the patients on whom a Type IV tympanoplasty was done is scheduled to have a fenestration operation soon The postoperative hearing status of the patients who had Types III and IV tympanoplasties is shown in Table I Labyrinthitis and other serious complications have not occurred in this series

TABLE I

Audiologic Results of Tympanoplasty Types III and IV

| Type | Avg db Gain | Avg P O Air Conduction Threshold Loss in db | Max. db Gain | Best P O Hearing Level in db Loss |
|---|---|---|---|---|
| III | 16 | 34 | 35 | 23 |
| IV | 14 | 38 | 32 | 27 |

## CONCLUSIONS

Tympanoplasty is a tedious and time consuming, but fascinating surgical procedure The hearing gain in this series has fallen short of what is reported to be obtainable, but I have been encouraged by the early postoperative results, and believe that tympanoplasty is the treatment of choice for most patients with chronic otitis media and mastoiditis

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## SOUTH CAROLINA SOCIETY OF OPHTHALMOLOGY AND OTOLARYNGOLOGY

The next joint annual meeting of the North Carolina Eye, Ear, Nose, and Throat Society and the South Carolina Society of Ophthalmology and Otolaryngology will be held in Asheville, N C, on September 14-17, 1958, at Grove Park Inn An excellent program is in the making The following guest ophthalmologists will be present Dr James A C Wadsworth, New York, N Y, Dr Arthur Gerard DeVoe, New York, N Y, and Dr Frank B Costenbader, Washington, D C The following guest otolaryngologists will be present Dr F W Davidson, Danville, Pa, and Dr Tom Rambo, New York, N Y A third otolaryngologist will be announced in the near future A good attendance is anticipated

For further information write directly to Dr George Noel, c/o Cabarrus Bank Bldg, Kannapolis, N C, or Dr Roderick Macdonald, 330 East Main St, Rock Hill, S C

# PARAORBITAL LESIONS *†

F HARBERT, M D ,

Philadelphia, Pa

This discussion will be limited to lesions which may cause signs and symptoms in the orbit and its contents, but which originate in areas adjacent to the orbit Conditions to be considered in differential diagnosis will be enumerated and illustrated by cases in my experience Anatomically, the paraorbital area consists of

1 Nose and Sinuses

2 Nasopharynx

3 Cranial cavity

4 Skin of lids and adnexa

## GENERAL DISORDERS

Osteitis deformans (Paget's), osteitis fibrosa, and leontiasis ossea give characteristic X-ray findings The lipodystrophies may involve membrane bones adjacent to the orbit Diabetes insipidis and biopsy confirm the diagnosis Fibrous dysplasia, sometimes called ossifying fibroma, begins in childhood with slow progression and is often apparently quiescent in the adult It is characterized by absorption of normal bone and replacement by adult fibrous tissue in which new bone appears Histologically there is sharp demarcation between normal bone and new growth and no periosteal or other host reaction Radiographically the margins are vague

## INJURIES

The tissue of the lids and bulbar conjunctiva are notoriously subject to extravasations of blood, giving the classical black

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*Read at the meeting of the Eastern Section American Laryngological Rhinological and Otological Society Inc Philadelphia Pa. Jan 9 1958

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eye It is interesting to note that this hemorrhage does not necessarily come from direct trauma, but is often due to diapedesis through delicate capillaries The capillaries on the lateral aspect of the bulb are most prone to this, as shown by the frequency with which extravasation occurs here as a result of excessive coughing and in rhinoplasty

Epiphora and lid edema is common as a reaction to trauma or infection of the paraorbital area Limitation of the globe and induration indicate orbital cellulitis, abscess, or cavernous sinus involvement In response to a blow, the skull and facial bones become deformed, with or without fracture This sudden deformation may cause a tear or injury to soft tissue even when fracture does not occur, as for example hematoma of the maxillary sinus associated with orbital edema

BENIGN NEOPLASMS OF NOSE, NASOPHARYNX AND SINUSES

Adenoma }
} usually polypoid
Angioma }
Chondroma
Endothelioma
Fibroma
Fibrous dyplasia (ossifying fibroma)
Hamartoma
Juvenile angiofibroma
Lipoma
Mixed tumor
Myxoma
Neurilemmoma
Neurofibroma
Odontoma
Osteoma
Papilloma (inverting)
Plasmacytoma
Teratoma

TABLE I

Blows to the zygoma often cause fractures of the orbital margin inferiorly and laterally in conjunction with fracture of the zygomatic arch In evaluating such a fracture it is imperative that alignment of the delicate plate-like floor of the orbit be determined radiographically It is well to remember that fractures here may not be demonstrable by routine films If fragments are depressed into the antrum enophthalmos results when edema subsides This used to be called fat atrophy following injury, but is due to herniation of orbital contents into the maxillary sinus by scar contraction Replacement and maintenance of these fragments by packing, inflated balloon, etc, through a Caldwell-Luc incision is usually necessary

Emphysema of the orbit may be associated with fractures involving the sinuses, particularly the ethmoid Emphysema occurring without trauma may indicate an eroding lesion, *e g* ethmoid osteoma

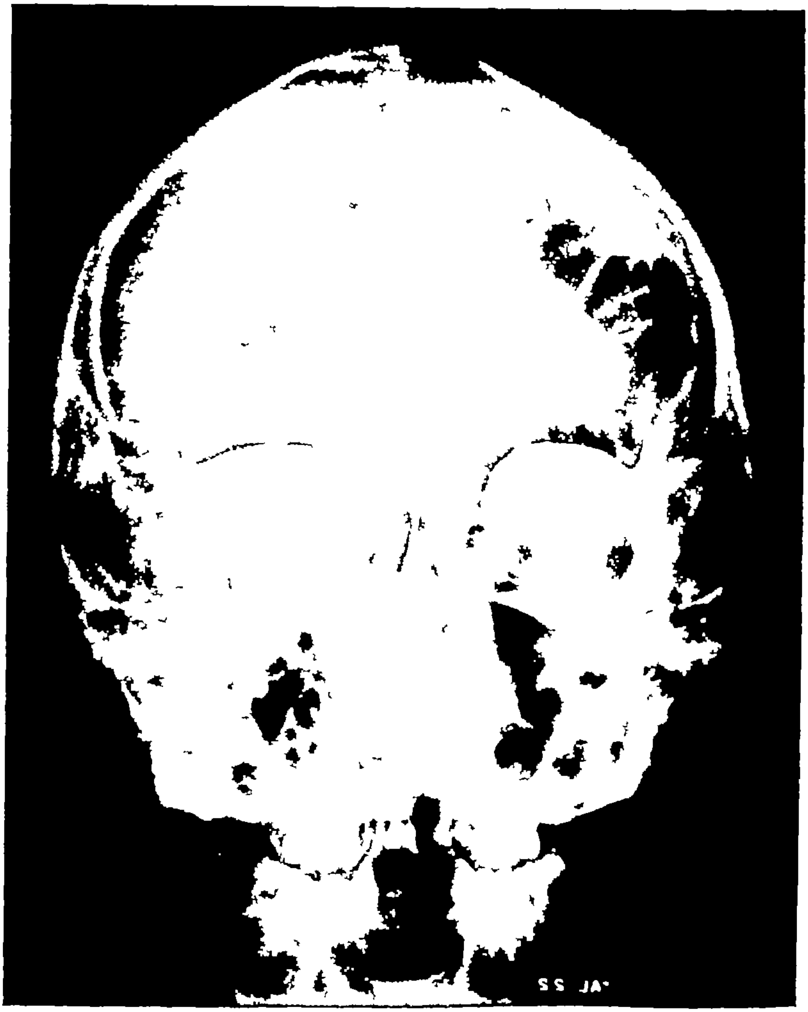
MALIGNANT NEOPLASMS OF NOSE, NASOPHARYNX, AND SINUSES

| Carcinoma | Sarcoma |
|---|---|
| Adenocarcinoma | Angiosarcoma |
| Ameloblastoma | Chondrosarcoma |
| Chordoma | Fibrosarcoma |
| Epidermoid carcinoma | Lymphosarcoma |
| Neuroblastoma | Malignant schwannoma |
| Transitional cell carcinoma (lymphoepithelioma) | Melanoma |
| Undifferentiated carcinoma | Myeloma |
| | Osteogenic sarcoma |
| | Reticulum cell sarcoma (Ewings) |
| | Rhabdomyosarcoma |

TABLE II

## NOSE AND SINUSES

The relation of the nose and sinuses to the orbit is characterized by thin bony partitions with frequent dehiscences, absence of orbital lymphatics, and free anastomosis of veins We may consider that blood from the sinuses drain into the cavernous sinus via the orbit, and in sinusitis, extension to the orbit is by phlebitis The frontal sinus is insignificant below age seven, and maxillary sinusitis causes orbital complications only when there is osteomyelitis The sinuses account for 60 per cent of orbital infections Of these the frontal is most often the cause, except in younger children where ethmoid disease is more important[1] Granuloma may be specific, *e g*



Chondrosarcoma of the nose causing unilateral proptosis and bilateral visual impairment

Fig 1 Indeterminate findings by usual views

scleroma, yaws, syphilis, etc, or non specific The midline (lethal) granuloma remains an enigma Cysts such as dermoid and dentigerous may extend into the orbit

## SINUSITIS

Acute fulminating frontal sinusitis may occur in younger individuals with normal sinuses, often after swimming Acute

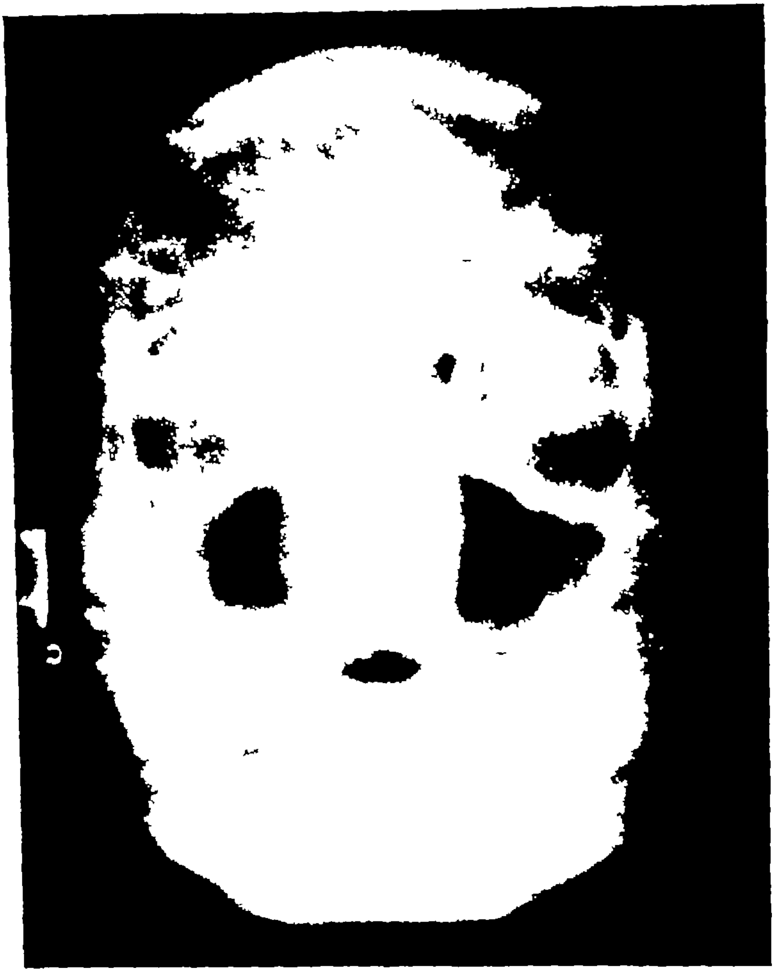


Fig 2 Planigraphic demonstration of tumor

Exacerbations of chronic disease, or recurring acute attacks indicate underlying pathology such as inadequate aeration Obstruction is in the nasofrontal connection, and not in the nose Such procedures as removal of nasal polyps, infraction or amputation of the middle turbinate, and submucous resection may be indicated, but rarely relieve the basic obstruction

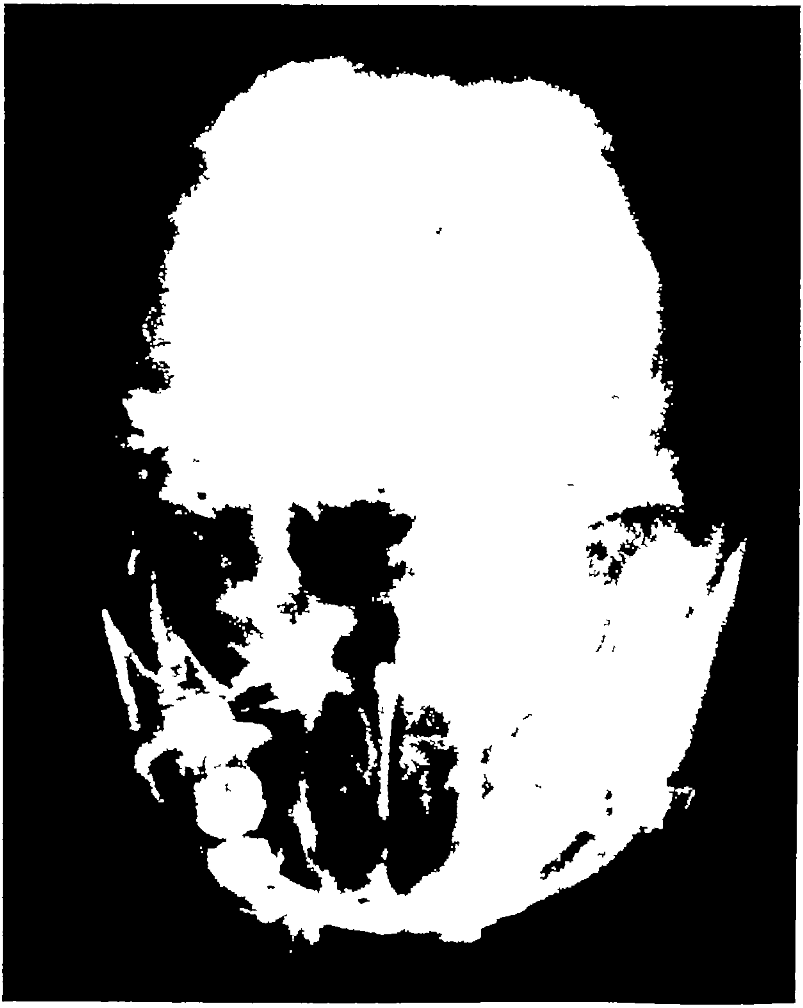


Fig 2a. Basal view of skull showing encroachment on nasopharyngeal airway and obliteration of foramana and Eustachian tube

Nasopharyngeal lymphosarcoma causing proptosis paralysis of the VIth nerve and extension to middle and external ears on admission Complete regression under X-ray therapy with subsequent metastasis to lungs

Bone reacts to infection by either proliferative or destructive changes The former is commonly seen as a condensing osteitis of the sinus wall, and usually indicates a chronic and milder process than demineralization Sinus tracts may extend to the lids or orbit Local destruction of marrow (osteomyelitis) indicates a more acute process Because of intimate venous connection between marrow spaces, dura, and periorbita, both intracranial and orbital complications may occur in the osteolytic type Reactive orbital edema is common with acute sinusitis

*Mucocele* Mucocele causes erosion and absorption of adjacent bone with encroachment on the nose, orbit, and dura The frontal sinus is most commonly involved in adults, and the ethmoid in the young The maxillary and sphenoid sinuses are rarely affected The symptom calling for medical attention is usually painless deformity—in the case of the orbit proptosis Diagnosis is usually made by X-ray, which shows thinning of walls and obliteration of normal scalloping of the frontal sinus or coalescence of ethmoid cells Periodic ophthalmoplegic migraine and proptosis may indicate sphenoid mucocele If a mucocele exposes both the periorbita and the dura there may be a pulsating exophthalmos

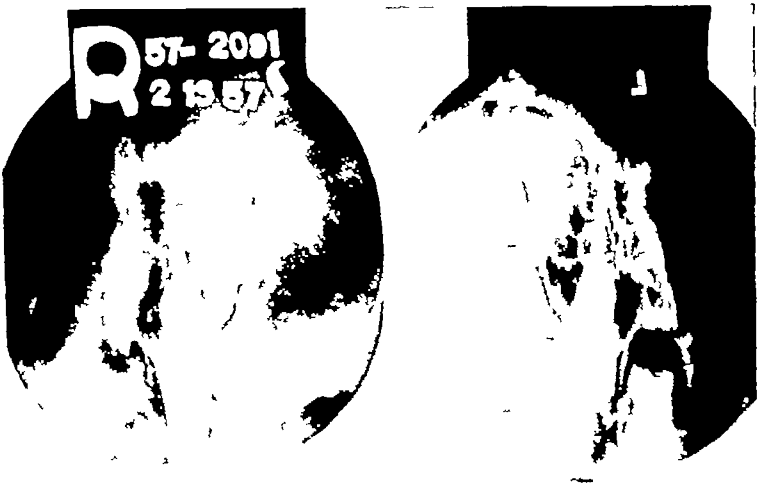


Fig 2b Mayers views showing coalescence of external coral antrum and adjacent cells

*Neoplasms* Tumors involving the orbit occur approximately as follows [6] primary 60 per cent, paraorbital 30 per cent, metastatic 10 per cent

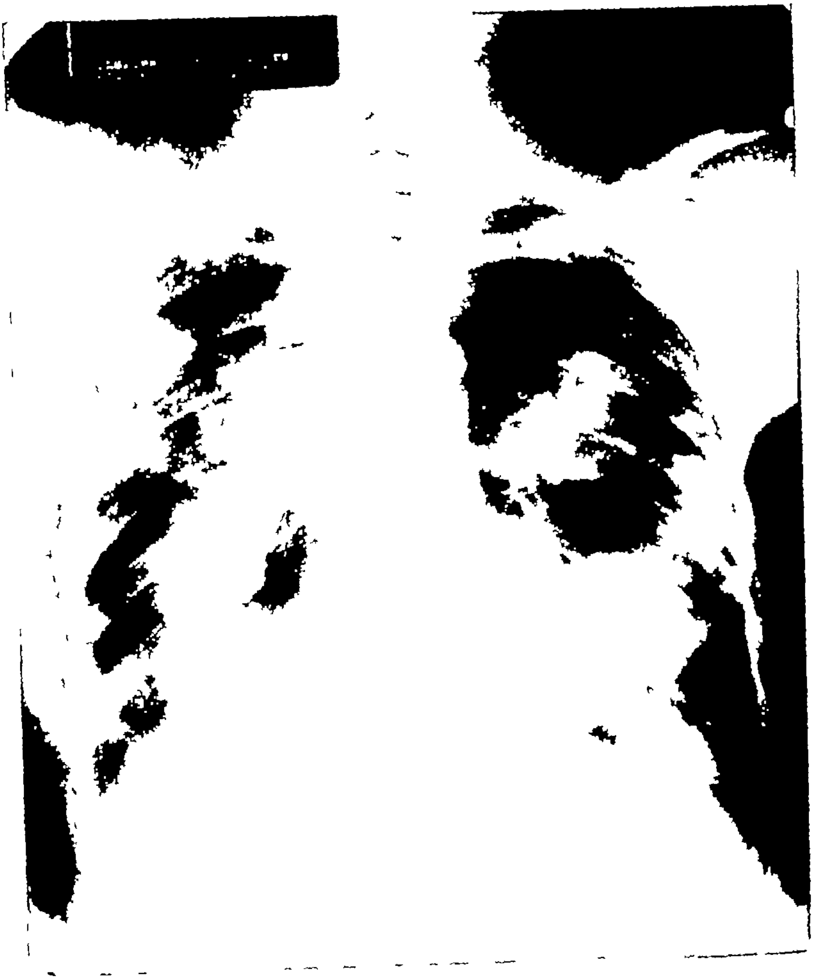


Fig 2c Pulmonary metastasis

The eye is able to adapt to slow invasion of the orbit, as by a benign tumor without the development of diplopia, or limitation of excursions even when proptosis is marked The development of diplopia and reduced mobility with little proptosis is, therefore, an indication of a rapid orbital invasion, and is more characteristic of a malignant tumor [1]

Nasal polyps of the mucoid type practically never encroach on the orbit, but the presence of nasal polyps may mask more deep seated disease Repeated biopsies, sometimes through external incisions, may be necessary to establish the presence of a neoplasm The use of iodized oil, Papanicolaou smears, and aspiration biopsy have questionable value, in that a positive finding must be confirmed by open biopsy, and a negative finding is valueless[3] The presence of unilateral polyps and discharge, or epistaxis, particularly warrants thorough study[3]

Osteoma is an encapsulated bony tumor originating from disturbed or displaced cartilage Cortical, cancellous, and mixed varieties are recognized They are slow growing and produce symptoms by obstructing passages causing mucocele or secondary infection, sinus tract formation, or encroaching on adjacent orbital or cranial areas The frontal sinus is involved in one-half of the cases, the maxillary in 10 per cent, and the ethmoid in the rest[1,4] Sphenoid involvement is very rare

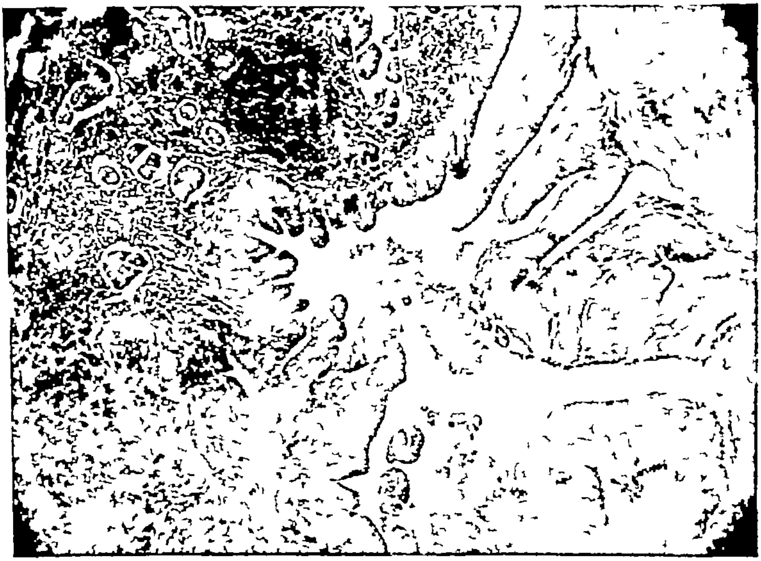


Fig 3 Basal and squamous carcinoma of lids with extension into orbit requiring exenteration and metastasis to cervical lymph nodes

Carcinoma of the paranasal sinuses constitute only 0 2 per cent of all carcinoma[3] Of these by far the greatest number originate in the antrum, and the balance in the ethmoid The frontal and sphenoid are usually secondarily involved[1] Males are affected twice as often as females for both osteoma and carcinoma Unless the tumor originates superficially and causes early obstruction or bleeding, the diagnosis is usually made late X-rays usually fail to reveal the full extent of the lesion

## NASOPHARYNX

Malignant tumors of the nasopharynx constitute about 3 per cent of all malignancies, and are most often epidermoid in the adult and sarcomatous in the young They may spread to the orbit, intracranially, or along the Eustachian tube The peritubal syndrome (triad of Trotter) consists of deafness due to serous otitis media, neuralgia due to involvement of the mandibular division of the Vth nerve and palate palsy The syndrome of the orbital apex (petrosphenoid syndrome) consists of palsy of one or more nerves II, III, IV, V, VI, and the sympathetic (Horner's syndrome) The orbit becomes involved by extension in the foramen lacerum along the carotid artery to the superior orbital fissure, or by extension from the pterygoid space to the inferior orbital fissure Deep seated parotid tumors may affect the orbit by the latter route Some primary malignant lesions may not be recognized, even in the presence of cervical metastasis, which occurs in 75 per cent of cases In 50 per cent, the first symptom is ocular, *viz* diplopia, pain, or reduced vision Fifteen per cent have symptoms referable to the ear—pain, fullness, deafness, as the initial complaint[1] Any case of otherwise unexplained cervical adenopathy, otalgia or deafness, facial pain or anesthesia, or diplopia, should have a thorough examination of the nasopharynx and biopsy of any suspicious lesions

Juvenile angiofibroma occurs usually in male adolescents, grows to about age 25 and then recedes It may originate from any part of the base of the skull, often with multiple attachments It absorbs adjacent bone by slow growth, and may extend intracranially into the orbit, nose, sinuses, and sphenopalatine fossa Recurrent severe epistaxis, nasal obstruction, or secondary sinusitis is common Biopsy of such a tumor had best be done in the operating room

Chordoma is a tumor originating from the cranial end of the notochord It may occur in the nasopharynx, sphenoid or intracranially X-ray may show a bony defect at the site of the tumor A partial list of other tumors to be considered is shown in Tables I and II

## SKIN AND ADNEXA

Malignant tumors of the skin may extend into the orbit Lid tumors are frequently baso-squamous It is well to remember that while basal cell tumors practically never metastasize, the baso-squamous type do When an epidermoid lesion involves only soft tissues, treatment by either radiation or surgery may be considered When bone is involved the prognosis is grave, and treatment by any method is difficult, but surgery provides a better prognosis than radiation Acute inflammatory processes of the skin or lachrymal sac may cause orbital cellulitis or abscess, while chronic lachrymal sac infections may produce sinus tracts

## CENTRAL NERVOUS SYSTEM LESIONS

Central nervous system lesions, causing orbital symptoms may be considered under the heading of tumors, cavernous sinus thrombosis and A V aneurysm

Probably the most common intracranial tumor associated with the orbit is meningioma arising in the vicinity of the sella or sphenoidal ridge The latter may extend into the orbit as well as intracranially Marrow bone adjacent to such a tumor often reacts by causing hyperostosis while cortical bone is absorbed Characteristic X-ray findings and the syndrome of the orbital apex are diagnostic Proptosis and optic atrophy usually precede neurological findings and pituitary dysfunction Pituitary tumors extending into the sphenoid may be best treated by the otolaryngologist

Cavernous sinus phlebitis is usually due to toxic swelling of the endothelium and thrombosis to stasis The original source of infection may be as follows

*1* Skin of the face (especially the lids, lip, and scalp, via angular and superior ophthalmic veins)

*2* Nose· (via ethmoid and ophthalmic veins)

*3* Teeth (via pterygoid plexus and inferior ophthalmic vein)

*4* Ear and Mastoid (from lateral sinus or via petrotympanic fissure to pterygoid plexus and inferior orbital vein)

*5* Throat (via pterygoid plexus and inferior ophthalmic vein)

Cavernous sinus thrombosis may also occur in blood dyscrasias and septicemia

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# THE WONDER DRUGS—A PSYCHOSOCIAL PHENOMENON *

LESTER L COLEMAN, M D ,

New York, N Y

It is said that the history of civilization has as its mirror the history of medicine The art and practice of medicine has been intimately interwoven into every phase of man's accomplishments, for always the history of a nation's economy, growth, intellectual and artistic attainments have been dependent upon the health of its people

Revolutionary concepts in science and medicine have through the ages opened new horizons and new vistas for the study of man Every generation seems to have brought with it newer accomplishments, newer therapeutic techniques, newer diagnostic facilities, all bringing with them a growing feeling of encouragement and hope

All therapies from time immemorial have had as a valuable ally an aura of magic and sorcery Even today disease is still enshrouded by a veil of mystery Invisible pressures, apparently beyond the control of the individual, seem to exert forces that convert health to illness Disease seems to be endowed with special malice governed by an invisible mystic force Fevers, chills and anxieties uncontrollable and unyielding have been recorded as having these mysterious overlays Disease is considered capricious and punitive, especially by those plagued with guilt for real or fancied sins

Mores are different in all civilized and primitive societies The character of the taboos may vary with special enlightenment, but the violated taboo always suggests that disease is punishment for sin and guilt The invisible devil exerting his malicious charms is given special credit for the causes of disease Civilized societies impose similar supernatural quali-

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ties to the mysteries of modern-day illness We, too, seek the cause of disease in quasi truths and fiction, departing slightly from the primitives who seek theirs with magico-religious incantations Magic, the unexplained, is as vital an element in the healing as in the cause of disease

The potency of the sorcerer and the efficiency of his art, regardless of the nature and cause of sickness, lies in the magical healing qualities of his prescription The greater the rarity, the greater the difficulty in obtaining it, the greater the expense, the greater is the potential curative power of that drug Rarity is the exploitable element in the sorcerer's armamentarium of magic Exorcism, one of the precursors of the psychosomatic concept, was a potent technique against any spiritual intrusion The magico-religious implications of the etiology and cure of diseases has its specific roots in the social and economic structure of any particular society Therapy in primitive society is rational in terms of its particular world of magic and the supernatural For these primitives it is logical and predicated on the faith in the tribal healer The rapport between the savage and the sorcerer, his medical consultant, is solidified by exquisite faith based on past accomplishments Witchcraft and black magic, born of scientific limitations in primitive society, has its exact counterpart in the medical practices of today's society

All therapy has evolved through distinct periods of ignorance and truth The parallel relationship between disease and therapy can be used for study of one or both At first all therapy was magical, mystical and religious, and had no basis in fact Therapy was then nonempirical and based on illogical postulates The next phase of enlighenment was the pre-scientific era when therapeutic procedures were based on abstract or metaphysical ideas, combined with the beginning of the empirical approach Later came the positivistic or early scientific attitudes toward therapy based on the study and observation of natural phenomenas Unfortunately, during this period there was as yet not enough interdisciplinary knowledge for the adequate explanation of these anatomical and physiological phenomena

The era into which we have grown with scientific maturity is one whose accomplishments are based on scientific postulates, scientific observations and thorough analysis Therapy attained its full maturity with the realization that no science can be isolated or insulated from all other biological, philosophical or social disciplines The therapeutic ultimum could only be attained by extensive interdisciplinary exchanges of all allied information

The advances and correlation of this interdisciplinary knowledge is rapidly bringing us to a peak of scientific accomplishment Physical, chemical, biological and social studies, combined with psychoanalytical disciplines, are all represented in this mature humanistic era of medicine Medicine incorporates these scientific studies, piloted by the physician who applies them for clinical therapy The horizons have thus been expanded for today's doctors They must not be burdened or limited by any sociological pressures and revert to ancient concept of therapy

Language is the basic means of communication between the doctor and the patient, yet each speaks a different language, one that needs amplification and explanation The confusion of this language barrier is elaborated because the patient seems to "hear with an accent" The patient listens but hears with a distortion born of the tensions and anxieties of illness Illness destroys the emotional stability of many patients, or at least alters it It is in this off-balance position that they first make contact with their doctors Long after the disease and its devitalization has passed, the doctor continues to be identified with painful symptoms, complaints, alteration of productivity and financial burdens Thus the physician evolves as a predatory subversive who parasitically thrives on the patient's misfortune

The doctor is considered by the patient as the possessor of infinite wisdom, and is invested with the cloak of symbolic reverence and adulation Subtle pressures are imposed upon him to maintain this precarious position of limitless knowledge Rarely is he permitted the luxury of saying "I don't know" or "I will find out" Answers are a must, even if fiction is substituted for fact Fiction thus created must later be denied or confirmed with additional fiction Errors thus become fixed in the mind of the patient who is convinced of the omniscience of his doctor For, a simple thought, cloaked in a polysyllabic phrase, can become a confusing enigma reaching culmination in wonderment and awe by the patient

There are many such paradoxes in the doctor-patient relationship that must be reconciled before complete solidification of this important unity is to be achieved Patients resent being emotionally and physically undressed and exposed to the intricate and labyrinthine investigations that seem to be aimed at the annihilation of their personal ego The doctor sometimes sadistically enjoys the authoritarian position that allows him to intrude into every crevice of the patient's life. Doctors have been enveloped with a halo of godliness for so long that they have grown to enjoy its magical potency

Many doctors are offended when their right to their godlike pinnacle of prominence is questioned They wear their protective cloak of godliness, fearing only that if defrocked they will reveal their human frailties and expose their medical inadequacies

The desperate need and impulse to "do something" is the doctor's response to anxiety superimposed on him by the patient The stress of fear and anxiety that invariably accompanies all disease makes urgent therapeutic action a necessity This stress is a profound pressure on the relationship between the patient and the doctor It is the same pressure of anxiety which expressed itself in sacrifices at the altar or in visits to the shrine of an oracle It is the same impulse that led primitives to search out the strange herb for concoctions for the sick Ignorance of the potential or the ingredient of the herb played no part in the motivations to give it Out of this sociological pressure has grown the philosophy of the placebo Medicine has never been divorced from this concept Implicit in the function of all drugs, with or without a specific pharmacological action, is the important emotional value of the placebo Even the antibiotics, used judiciously to destroy a specific organism have the distinct emotional overtones of the placebo

It is not my purpose to become too involved in general semantics or in psychoanalytical interpretations May I be forgiven if I recall that a fundamental to the relationship between the doctor and the patient is the need for dependence and perhaps a regressive infantile need for punishment The authoritarian personality, the protector, the physician becomes the embodiment of support and security of the parent Patients classified as placebo reactors with a distinct evidence of suggestibility are the passive dependent types who rely on the authority of the doctor

Any medication prescribed by the physician carries with it the hope of fulfillment and protection The medication takes on an emphatic projection of the doctor's personality and becomes in essence a symbol of support, of faith and even of spiritual wisdom The actual chemical ingredient has as a hallmark of authenticity the faith in the doctor's judgment There is then a skillful art in the balanced use of the placebo It is not a means of deception, of fraud or misrepresentation, yet there can be but a delicate semantic nuance between its honest and dishonest use When the placebo is used as a technique to disguise our scientific inadequacy, it is inexcusable When drugs with a placebo effect are endowed with supernatural powers to compensate for our limitations their use is also inexcusable The placebo can never be used to absolve the physician from the obligation to differentiate critically between the physical and emotional needs of the patient

Moral values and their interpretation have insinuated themselves into the controversy for and against the use of the placebo Lost in this controversy of morality were the specific needs and emotional equipment of the patient that dictated their use

Illness is a threat to the integrity of the patient The placebo as a specific form of therapy can serve as an additional tie between the doctor and the patient The need for all therapy diminishes in direct proportion to the growing strength of that binding tie Their strengthened relationship strips all therapy of affectations, pragmatic lies and purposeless distortions

The art of therapy is a discriminating art Factors apparently far removed from the etiology and diagnosis of disease determines therapeutic decisions The art of treatment is intimately a part of the intricacies of the doctor-patient relationship Drugs, especially the newer antibiotics, have become the property of both the doctor and the patient When the sulfonamides and later the antibiotics were introduced, the press rapturously exalted their supernatural powers These drugs were immediately considered as mystical throwbacks, first because their life-saving action was so poorly understood, and second because of their comparative rarity Rarity again became an element exploited by those who ascribed to these drugs the title of "wonder" Their physiological action and specific characteristics to defend the body against the invasion of attacking organisms were lost in the excitement of the newness Rather were the wonder-drugs considered as some magical derivative that had the specific power to exorcize all disease Modern medicine temporarily reverted to the magical, mystic phase of prescientific medicine

The sulfonamides and the antibiotics, by their very title of "wonder drugs" were given an extra mundane aura of magic They gracefully took their place among the many drugs about which there still persists an inherited feeling of mysticism Because the announcement of the discovery of the wonder drugs came to the laity at the same time that it came to the doctors, via press, radio and television, patients seemed to feel that they, too, had as great a proprietary right of possession of the drugs as did their contemporaries, the doctor, patients felt that unless the doctor actually discovered penicillin himself, he could not rightfully consider himself any greater expert in its administration than the patient himself From then on, so-called qualified experts sprang up everywhere Recovery from any illness and the correct pronunciation of the responsible drug fulfilled the basic requirements for admission to the lay society of therapists For a long time after Fleming discovered penicillin the importance of its contribution was overshadowed by endless discussions as to whether it was to be called peńicillin or penicillin If I recall correctly, a publication was released by a Committee of Eight which finally gave the news to the world, not of the great action of the drug, but of its correct and properly authorized pronunciation, penicillin.

Gleefully and rightfully the patient rubbed his hands in delight at the possibility that the physician would slowly become extinct. Dinner parties could always be rescued from boredom by a commiserating discussion of the dwindling need for doctors in the community. Here for the first time was an opportunity to volatilize their stored inner rages against the doctor, the golem of all illness. The immediate disappearance of all acute mastoid surgery was considered a kindness to mankind, but more important the first step in the total eradication of that parasitic vulture, the tonsil-snatching, septum-slicing butcher of butchers, the otolaryngologist.

Specialists in all other fields were being slowly eliminated, too, as the antibiotics were finding wider and wider use; in fact, the only field that seemed safe from the onslaught of the antibiotics was psychoanalysis, and it is now facetiously rumored that a potent antibiotic is in the making for covert homosexuality.

Chemotherapy and the antibiotics have taken a unique position in the important sociological relationship between the doctor and the patient. This position has as great a potential for good as it has for harm. The patient now demands and supports his demands for a specific drug, at a specific time, with a subtle threat. The special weapon, the ace in the hole to support his insistence is the "give or else law of no return." Either the doctor gives the antibiotic or the patient threatens to go somewhere else. Many patients have thus revolted from their previous position of subservience to enjoy new found control over the authority of the doctor. There was now a restoration of the balance of power which they had so reluctantly yielded to their physician. If I may be permitted the luxury of a pun, there is now an "intermycin intrigue" for the retention of the weapon of dominance.

Though this pressure may not always alter the integrity or the therapeutic motivations of the doctor, it may alter his approach to the treatment of that particular patient He recognizes that the patient will ultimately obtain the shot of wonder drug somewhere, and thus succumbs to the pressure of the patient's demands Loss of therapeutic integrity is coincidental with the position he forfeits when he becomes a tool buffeted by the whim and fancy of medical ignorance Having fallen into the pressure trap of the social use of the wonder drugs, he finds it difficult to extricate himself and is forced to perpetuate that initial error This is the penalty for giving too great importance to these drugs and indoctrinating the patients in their miraculous misconceptions

The demands for a rapid cure has forced the doctors into competition with each other and with themselves Speed of cure has become the critical value in the expansive pride of possession of the patient for "their" pediatrician, "their" obstetrician, "their" nose and throat doctor Speed of recovery always substantiates the magnified enthusiasm that makes their doctor "the chief of the department" or "the head of the hospital" To have less than "the chief" is a social disadvantage An unimportant doctor and an unimportant disease can be a social handicap in the caste-like system of "illnesses" New therapy, even when scientifically unconfirmed, adds special distinction Patients sometimes vie with each other for the special privilege of being an experimental "guinea pig" for a new antibiotic There is nothing more destructive to the vanity of the patient than the doctor's casual statement that "the disease was relatively unimportant and would have gone away by itself" Recently it became a sign of social distinction to have had the first case of imported Asian flu in the community

Antibiotics do not live by "molds" alone The virus is a sly little fellow that has slowly insinuated himself into the practice of medicine as a subversive character His position is made secure by those of us who exploit him to preserve the sanctity of our trade unionism The virus is dead, long live the virus Without him our inadequacies might be showing The virus flourishes luxuriantly on the nutrient medium of ignorance It can always be depended on to extricate us from any untenable medical position The virus is a comfortable refuge to explain the unexplainable It seems hardly fair to use the antibiotics so injudiciously and promiscuously to destroy such a valuable ally These two sociological elements, the virus and the antibiotics have joined forces and become a potent factor in our choice of therapy Many years ago the magical power of the sulfonamides was said to cure the first virus I ever encountered This was a six-day virus, a slow moving, unimpressive, undistinguished virus Next came the forty-eight hour virus, cured dramatically with penicillin The cure was fast, the drug was greater, the doctor was the greatest We are now in the jet propelled two-hour virus phase, cured by "my doctor" with the triple acting wonder drug that contains "god all" Time records for cure have been broken with regularity The cure now is so rapid that the patient barely has time to complain

Many truths are interwoven in this apparent facetiousness

Physicians and patients have been equally responsible for distorting the delicate balance of their vital relationship Patients had been given remarkably little credit for their capacity to understand the complexities of their medical problems, but almost invariably this apparent lack of understanding was based on our inability to explain, rather than on their inability to comprehend The laity is receptive to unconfused and undistorted medical information They welcome precise explanations of our discriminating decisions for or against specific use of the sulfonamides and antibiotics They now appreciate the disadvantages of the unbridled use of any drug, for they have learned, usually by sad experience, about the side effects and toxic reactions of these drugs They have a new and profound respect for the danger in the promiscuous use of any drug They have come to realize their inadequacy in guiding their own course of therapy

Physicians everywhere are relinquishing their position as a drug giving cult They are revolting against the social pressures of the patients who dictate their own antibiotic therapies, but with this revolt comes newer enlightenment and recognition that the emotional needs of patients cannot be supported by the promiscuous use or abuse of antibiotic therapy.

Fear and anxiety is a constant in the equation of health and illness, the evaluation, therapy, and prognosis of all disease must always include its recognition. For there is but one yardstick and one criterion by which we can actually measure the intensity, the severity and duration of an illness. The touchstone that guides us is only the return of the individual to complete serviceability and productivity. Not until the individual is totally rehabilitated and returns to serve as a functioning part of his home, job and community can that individual be considered free of his disease. The cessation of a cough, the return of fever to normal, the normal sedimentation rate or electrocardiographic findings are never the critical criterion of the return to health. For many patients who are ostensibly cured fail to take their place in society because of the devastating fear that the illness may soon return. It matters little whether the individual is not serviceable because he has had a heart attack or is afraid that he will have one. It matters little if a man cannot function because he has a carcinoma of the larynx or lives in constant fear that he will have one. The devitalization by fear of impending disease can be infinitely greater than the disease itself. Rehabilitation, reestablishment of normal patterns of living are the *only*—*yes, the only*—way that we can determine the efficacy of our therapeutic approach. It becomes evident, therefore, that no diagnostic or therapeutic concept of medicine can be divorced from an understanding of the psychological overtones that invariably accompany every disease to which the body is heir.

This harrassed world carries with it newly conceived fears that destroy our complacency. The practice of medicine notes with growing concern the increase in the number of patients who are overwhelmed with fear and anxiety, often completely out of proportion to the severity of their illnesses. Minor, relatively insignificant disease seems to catapult patients into an emotional tailspin by the propulsive force of their unreasoning fears.

For many, this fear is far more destructive than disease itself Anxiety seems to dominate their behavior during and sometimes long after their illnesses This anxiety is not characteristic of any one sex, age, occupation, social and intellectual level, or ethnic, religious and geographic group The timid, the stoïc, the shy and the stalwart seem to be equally affected by an overlay of fear about the illnesses they have, or more often think they have There may be variations of the intensity of the anxiety and the ease with which it can be alleviated, but no one appears to be completely free of it Patients, children, adolescents and adults are afraid, just afraid! Their fears as well as their illnesses determine how quickly and how well they will be reestablished in their schools, jobs or homes

Fear in itself is an illness The fear that we physicians observe in our offices is actually a communicable disease It is not transmitted by germs or by virus It is transmitted by humans to humans, sometimes unwittingly, sometimes in error, and sometimes purposefully For "Fear" is big business, and is often exploited by propaganda agencies under the guise of public medical education Fear of all disease, fear of heart disease, fear of cancer, fear of tuberculosis, fear of arthritis, fear of cataclysmic destruction by atom bombs, fear of economic upheaval, and now fear of the consequences of smoking, all become a never-ending bombardment against our inner security We have but to note the penalty paid by the public during their "education" about tobacco, Salk vaccine and Asian flu

Fear is everywhere, it is all-pervasive, slowly, deliberately it seeps into our physical, emotional and spiritual fibers To paraphrase Emerson, fear is a circle whose circumference is everywhere, and whose center is nowhere

Fear is a force, fear is an illness, it can alter the destiny of those who, by concession to this fear, distort their behavior in response to it It can play havoc with careers, social attainments, the relationship between husband and wife, and the relationship between parent and child

Fear does not "stand up to be counted," its greatest potency lies in being hidden Because it cannot be counted, it is not adequately charted in the statistics of the diseases of man, even though it ranks as one of the greatest threats to emotional and physical health

Fear, the product of this harried, frenetic Twentieth Century is a sociological phenomenon It activates many in their demand for miraculous therapy Uncontrolled it destroys the rational relationship between doctors and their patients Fear, as a disease and as an element in all disease, is readily communicated Fear flourishes in epidemic form and slowly insinuates itself into every facet of our civilization, but like all other diseases, fear is vulnerable and yields to its own miracle drugs—hope and courage, psychologic education and freedom from ignorance and superstition These, too, are wonder agents that are swinging the pendulum back to therapeutic sanity The wide spectrum of the use of wonder drugs must include judicious understanding and critical therapeutic evaluation Social pressures and prejudices must not dictate medical indications or specific choice of the "wonder drugs" if they are to survive in their rightful position as one of the greatest scientific contributions to mankind

162 East Eightieth Street

# IN MEMORIEM

## Gabriel Tucker, M D

1881-1958

Dr Gabriel Tucker, a native of Fairmont, W Va , died at his home in Rosemont, Pa , April 18, 1958

The degree of Doctor of Medicine was granted to Dr Tucker by Jefferson Medical College in 1905, and he practiced in Pittsburgh and its environs until joining the Army Medical Corps in World War I, in which he served abroad at Base Hospital 126

Widely known for his use of the bronchoscope and for his skill in the removal of lung cancers, he became Professor Emeritus of broncho-esophagology at the University of Pennsylvania Graduate School of Medicine and worked in the field as an associate of Dr Chevalier Jackson in the first bronchoscopic clinic at Jefferson Medical College Two years later he was named a charter member of the broncho-esophageal department upon the establishment of this clinic of the Pennsylvania Graduate School of Medicine

The Gabriel Tucker Fund for the department of broncho-esophagology was established in 1949 at the Graduate School by an anonymous gift of $200,000

Together with Dr Chevalier Jackson he conducted the first course in laryngeal surgery in the European medical schools

Dr Tucker was a member of the American Academy of Ophthalmology and Otolaryngology, from which he received the Honor Award in 1955, he was a past president of the American Laryngological Association and past secretary and chairman of the Section on Laryngology, Rhinology and Otology, of the American Medical Association, and was a Fellow of the American College of Surgeons

Surviving are his widow, three sons and four grand children

## SUBCOMMITTEE ON HEARING IN CHILDREN

The American Academy of Ophthalmology and Otolaryngology, through its Subcommittee on Hearing in Children of the Committee on Conservation of Hearing, has been conducting a long-term nationwide study of problems relating to the conservation of hearing in children The specific aims are to develop the most efficient case-finding methods and to use these methods in estimating the magnitude of the problem in the country, to study state laws and review current practices and facilities for rehabilitation of hearing impaired children, to help develop methods for medical and surgical rehabilitation standards, and ultimately to use the Subcommittee findings in assisting professional workers to improve and enhance programs in hearing loss

In the second year of operations, a full-time Executive Director has been engaged, and offices established at the Graduate School of Public Health, University of Pittsburgh An initial study is being conducted in Pittsburgh to identify early medical signs and symptoms which may indicate danger of hearing impairment, to measure the psychological, social and other effects of such impairment and to develop efficient and economical methods for the testing of hearing in children The Pittsburgh study is a cooperative effort among the following The Subcommittee on Hearing in Children, the Graduate School of Public Health and the School of Medicine of the University of Pittsburgh, the Pittsburgh Board of Public Education, and the Allegheny County Department of Health

The members of the Subcommittee on Hearing in Children are Dr John E Bordley, Baltimore, Dr Victor Goodhill, Los Angeles, Dr Hollie E McHugh, Montreal, Dr S Richard Silverman, St Louis, and Dr Raymond E Jordan, (Chairman) Pittsburgh An advisory committee of consultants from the University of Pittsburgh includes Dr Samuel M Wishik, Dr Leo G Doerfler, and Dr Isidore Altman Grants from the United States Children's Bureau through the Pennsylvania Department of Health and from the National Institutes of Health are providing financial support

# REINE HUMBIRD MYERS FELLOWSHIPS IN AUDIOLOGY AND HEARING SOCIETY ADMINISTRATION

The American Hearing Society and its member agency, the St Paul Hearing Society, announce two Reine Humbird Myers Fellowships for a two-year program of graduate study at Northwestern University, annual stipend $3,000, for students interested in a career combining the professional and executive responsibilities of Hearing Society work

Fellowships are open only to students who are acceptable to the Graduate School of Northwestern University, and who intend to take key positions in local Hearing Societies upon completion of the Fellowship training in Administrative Practices, Agency Procedures, Clinical Audiology and Speech Pathology

The program covers two calendar years The sequence of study will ordinarily lead to the Master of Arts degree Studies include courses in phonetics, basic audiometric techniques, speechreading, auditory training, and speech development, psychology of deafness, community programs in audiology, hearing aids and their selection, advanced audiometry, anatomy of the hearing and speech mechanisms, principles of speech correction, and elective areas The program also includes courses in social work, plus clinical experience and field activities

The resources of the Graduate School of Northwestern University are combined with the educational facilities in social work found in the Chicago area Special opportunities for practical experience are available at the Chicago Hearing Society and in clinics maintained by Northwestern University

Each candidate must submit to the American Hearing Society (a) transcripts of his academic record, (b) a personal statement describing his background and expressing his professional aims and goals, and (c) names of five references, including at least one college instructor and one employer or work supervisor The candidate must also apply for admission to the Graduate School of Northwestern University, and must notify the School of Speech at the University that he is seeking a Reine Humbird Myers Fellowship

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## INSTITUTE ON INDUSTRIAL DEAFNESS

Colby College, Waterville, Maine, presents the Sixth Annual Institute on Industrial Deafness, August 11-20 inclusive Please note that the course has been extended for three days in order to include engineering for noise control Its objective will be to train physicians interested in the problem, nurses, plant engineers and others in initiating and conducting hearing conservation programs in noisy industries The course includes basic otology, audiometry, noise measurement, ear protection and methods of noise control Class is limited to approximately twenty participants

The fee for the course is $250 and includes tuition, room and board The first week will constitute a complete course for doctors and nurses, and the reduced fee for this will be $200 Application should be made to Mr William A Macomber, Colby College, Waterville, Maine

# DIRECTORY OF OTOLARYNGOLOGIC SOCIETIES

(Secretaries of the various societies are requested to keep this information up to date)

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# STAPES OPERABILITY

## Pathological Indications for Mobilization and Fenestration Surgery *†

J BROWN FARRIOR, M D ,

Tampa, Fla

In recent years we, as otologists, have learned many techniques for mobilization of the stapes in otosclerotic deafness Through one technique or another, it is now possible to mobilize a very high percentage of stapes Even after complete mobilization many of these will show a prompt recurrence of the deafness, because the pathological involvement was beyond the limits of stapes surgery As otologists we must learn not only the new techniques, but also their pathological limitations

Initially the technique of the stapes mobilization operation was indirect, that is, all pressures were applied to or through the head and neck of the stapes With this basic indirect technique, primary hearing improvement was obtained in about one-third of the cases, and when mobilization was technically complete, a high percentage of these maintained the hearing improvement With this indirect approach, we were mobilizing only those cases with limited pathological involvement, and these pathologically favorable cases tended to maintain their hearing improvement

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*Presented at the meeting of the Southern Section of American Laryngological Rhinological and Otological Society Inc. Memphis Tenn Jan 25 1958

†From Southern Foundation of Better Hearing Tampa Fla.

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Today the indirect approach is largely replaced by a direct surgical attack upon the footplate and the disease process itself Now the percentage of primary results has almost trebled, and is no longer limited by the strength of the crura, it is limited only by the boldness of the surgeon and a few completely inoperable stapes With chisel, picks and drills, the enthusiastic surgeon can temporarily mobilize most all stapes The primary results have increased, but the incidence of re-fixation has also multiplied with this direct attack on the extensively diseased stapes

If we are to continue to attack these extensively diseased stapes and reduce the incidence of re-fixation, we must proceed with excavation of the footplate and the application of prosthetic crura (Shea[1]), or we must declare more stapes inoperable Extensive oval window surgery may prove to be worth while, and is worthy of investigation It may prove to be applicable in certain types of pathological involvement, but there will remain specific pathological limitations

As we approach the pathological limitations of stapes surgery (indirect, direct, or oval window) we arrive at the pathological indications for the fenestration operation The fenestration operation has received a wide variety of reputations By the early 1950s it had reached a standard of perfection that produced a very high percentage of grateful and happy patients, a percentage greater than the ear surgery of 1957, however, some still judge the fenestration operation by its reputation of the early 1940s and regard it only as surgery of the last resort The fenestration operation is a highly reliable and accurately predictable operation, it remains the master surgical procedure which will restore worthwhile and lasting hearing improvement in a high percentage of suitable cases which are beyond the pathological limits of stapes and oval window surgery

The thesis of this study is that there are specific pathological indications for stapes surgery and specific pathological indications for fenestration surgery, also, that in stapes surgery there are specific pathological indications for the variations of the indirect and direct surgical approach To date otologists have used the chance approach to stapes surgery with the attitude of try, and try again, and some have tended to exclude the fenestration operation until the stapes mobilization has failed, and failed again Although we can never draw fine lines of differentiation on the operability of the stapes, it is my hope that an appreciation of the tremendous variations in the pathology of the stapes will lead to an understanding of the broader classifications of the favorable, unfavorable and inoperable stapes

A stapes is called favorable when the anatomy and pathology lend themselves to stapes surgery, and when the prognosis for maintained mobilization and hearing improvement is good

A stapes is unfavorable when it can be mobilized but the pathology indicates that the prognosis is guarded A stapes is inoperable when pathologically it cannot be mobilized or, if mobilized, refixation is almost certain The classification is a surgical opinion of the existing anatomy and pathology, and is not dependent upon technical success or failure

At the meeting of the American Academy of Ophthalmology and Otolaryngology in October, 1957, I presented preliminary opinions and classifications of the anatomy and pathology of the stapes and their effect upon the operability of the stapes We are on the threshold of defining the operability of the stapes, based upon the anatomical variations and the type of pathological involvement This work is here republished with corrections, illustrations, additions and elaborations (Farrior 2a and b)

## STAPES OPERABILITY

The operability of the stapes is dependent upon the type of anatomical development and the pathological involvement Anatomically the footplate of the stapes may be superficial or in a very deep niche The first is most favorable for mobilization surgery, while with the deeply placed footplate the crura tend to become involved in the otosclerotic process, making the stapes either unfavorable or inoperable for mobilization surgery

Pathologically the otosclerosis may involve only the anterior edge of the footplate, or it may involve varying degrees of the footplate, crura, or even the head and neck of the stapes The simple footplate involvement is very favorable for mobilization surgery, while the complete otosclerotic involvement is inoperable, and is a positive indication for the fenestration operation

CHART I

Anatomically variations in the depth of the footplate and angulation of the crura alter the operability of the stapes (see Figs 1, 2 3) A superficial footplate with upright crura is the most favorable anatomical development for mobilization surgery

| A.—Depth of the Footplate of Stapes | Operability (Prognosis) |
|---|---|
| 1 Superficial | Favorable |
| 2 Moderately superficial | Less Favorable |
| 3 Moderately deep | Unfavorable |
| 4 Deep | Unfavorable |

| B —Angulation of Crura | Operability (Prognosis) |
|---|---|
| 1 Upright | Most Favorable |
| 2 Downward tilt (free) | Less Favorable |
| 3 Downward tilt (fixed) | Unfavorable |
| 4 Upward tilt | Less Favorable |

| C —Strength of Crura | Operability (Prognosis) |
|---|---|
| 1 Weak Crura | Vulnerable |
| 2 Medium Crura | Mod Vulnerable |
| 3 Strong Crura | Invulnerable |
| 4 Atrophic Crura | Inoperable Footplate |

The purpose of this presentation is to demonstrate the varying anatomy and pathology of the stapes and, in so doing, to define the operability of the stapes

## ANATOMICAL VARIABLES

The position of the footplate may alter the operability of the stapes (see Chart I)

If the footplate of the stapes is very superficially placed, the otosclerotic involvement will usually be thin, and there is no anatomical tendency for the otosclerosis to involve the crura (see Fig 1) If, on the other hand, the footplate of the stapes is in a deep niche, the crura tend to become tilted downward and thus easily contact the inferior lip of the

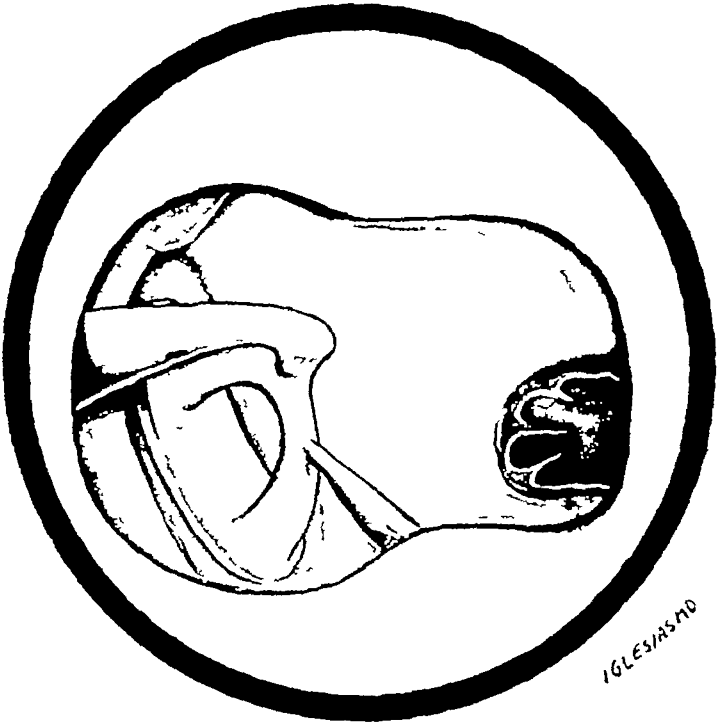

Fig 1 Anatomically when the footplate of the stapes is superficially placed and the crura are upright the otosclerosis tends to remain localized to the level of the footplate This figure illustrates a superficially placed footplate with upright crura and a small focus of circumscribed anterior footplate otosclerosis (see Chart I) For stapes surgery this is the most favorable anatomical development and pathological involvement.

oval window This predisposes toward otosclerotic involvement of one or both crura (see Fig 2), or complete otosclerotic filling of the oval window niche With a deep footplate, the crura will occasionally tilt upward to contact the Fallopian canal (see Fig 3) As the pathology progresses the operability becomes unfavorable to inoperable

The strength of the crura does not greatly alter the operability of the stapes with the direct surgical attack upon the footplate True, if the crura are weak or friable this predisposes toward their fracture, but too much pressure on the crura is a surgical error rather than the cause of inoperability

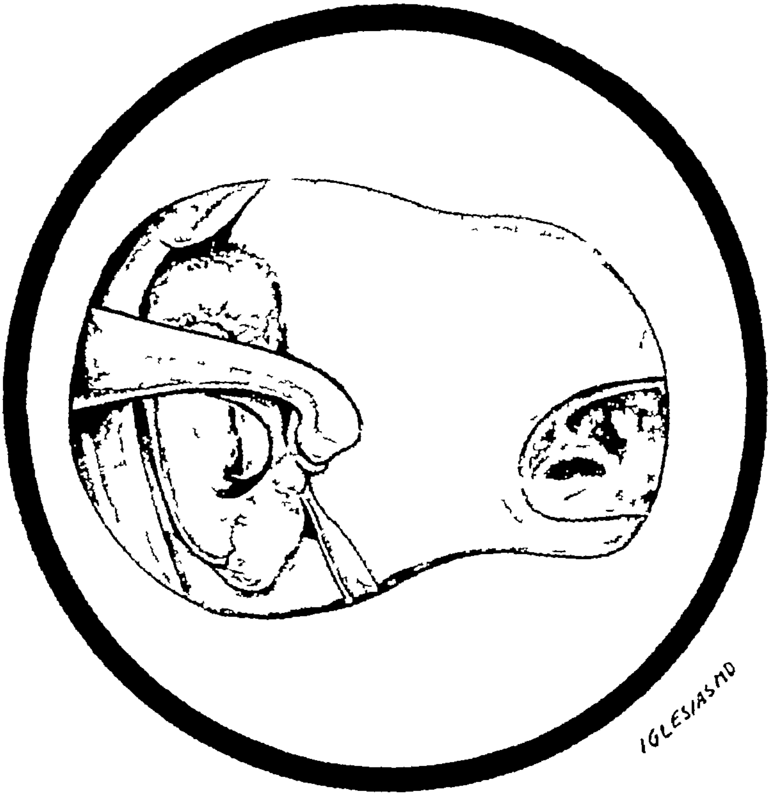

Fig 2 Anatomically when the footplate of the stapes is deeply placed in the oval window niche the crura tend to tilt downward and contact the inferior lip of the oval window niche This contact predisposes toward otosclerotic fixation of the crura and such crural otosclerosis alters the operability of the stapes (See Chart I) As re-fixation is prompt bi-crural otosclerosis is pathologically beyond the operable limits of manipulative operations on the total stapes

Atrophy of the crura is generally associated with complete footplate otosclerosis which is in itself inoperable Translucent red crura are the most friable while white crura will withstand the greatest amount of manipulation As others may wish to include a classification of crural strength, this is included in Chart I

## PATHOLOGICAL VARIABLES

### I LOCATION OF OTOSCLEROSIS

The location and character of the otosclerosis greatly alters

## CHART II—PATHOLOGICAL VARIABLES

The location and extent of the otosclerosis are the most important single factors in determining the operability of the stapes Originally I believed that the per cent of involvement of the footplate was the most important factor At the present time I believe that the thickness of the otosclerosis and involvement of the crura have the greatest effect on operability

| A. Location of Otosclerosis | Operability |
|---|---|
| I Type of Otosclerosis | |
| 1 Circumscribed | Favorable (see Fig 6c) |
| 2 Diffuse | Unfavorable (see Fig 6d) |
| II Footplate Otosclerosis (Fig 4a b c d) | |
| 1 None | Favorable |
| 2 Anterior Footplate | Favorable |
| 3 Posterior Footplate | Favorable |
| 4 Superior Marginal | Unfavorable |
| 5 Inferior Marginal | Unfavorable |
| 6 1/4 Footplate Involved | Favorable |
| 7 2/4 Footplate Involved | Less Favorable |
| 8 3/4 Footplate Involved | Unfavorable (Thick) |
| 9 Complete Footplate (thin) | Favorable (thin) (see Fig 6a) |
| 10 Complete Footplate (thick) | Inoperable (thick) (see Fig 6b) |
| III Crural Otosclerosis (see Fig 5a b c d) | |
| 1 None | Favorable |
| 2 Anterior Crus | Favorable |
| 3 Posterior Crus | Unfavorable |
| 4 Bicrural Anterior and Posterior Crura | Inoperable |
| 5 Apical | Inoperable |
| 6 Cervical | Inoperable |
| IV Round Window Otosclerosis | |
| 1 No Otosclerosis | Favorable |
| 2 Marginal Without Closure | Favorable |
| 3 Partial Closure | Unfavorable |
| 4 Complete Closure | Inoperable for Either Mobilization or Fenestration |

the operability of the stapes (see Chart II) Otosclerosis, which alters operability, may involve the footplate of the stapes, the crura of the stapes, the neck of the stapes or the round window

The two basic types of otosclerosis are circumscribed and diffuse—Fowler [3] Circumscribed otosclerosis is in general the type which responds best to mobilization surgery, providing the location and anatomy are favorable Stapes surgery is rarely of lasting value in diffuse otosclerosis which extends over the entire promontory Eventually we may learn that circumscribed and diffuse otosclerosis are separate diseases

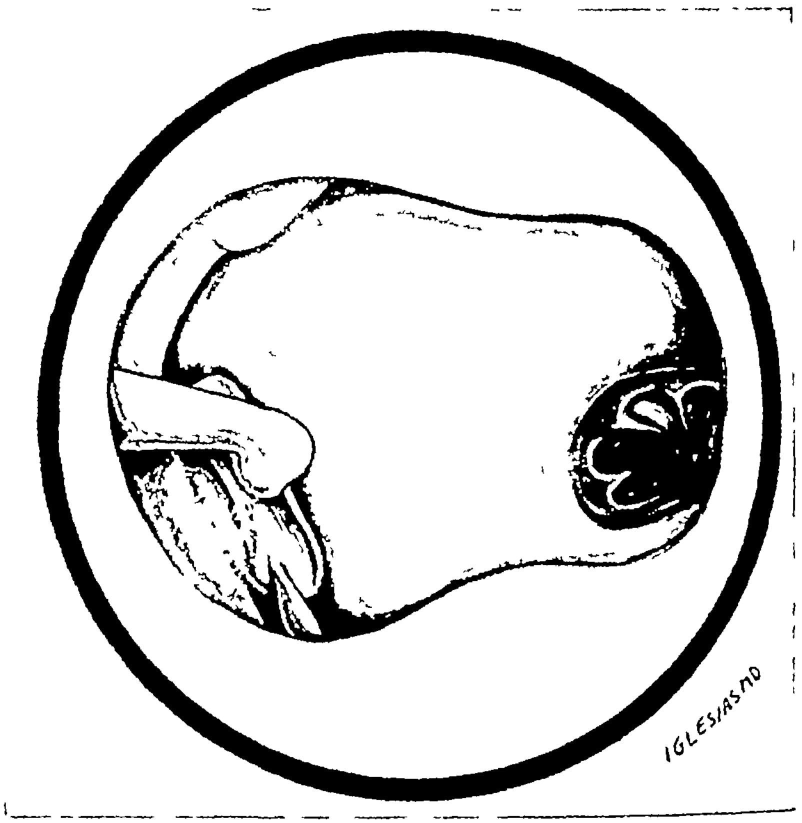

Fig 3 Anatomically when the footplate of the stapes is deeply placed in the oval window niche the crura will sometimes tilt upward to contact the fallopian canal This contact predisposes toward otosclerosis or postmobilization scar fixation between the crura and the fallopian canal (See Chart I)

From clinical experience, it seems that circumscribed anterior footplate otosclerosis is most favorable for mobilization surgery (see Fig 4a) Posterior footplate otosclerosis is equally favorable, but occurs less frequently (see Fig 4b) Superior marginal (see Fig 4c), and inferior marginal (see Fig 4d), are less favorable, for they tend to involve the sides of the crura The degree of involvement of the footplate is significant, and its influence upon operability is intimately associated with the thickness of the otosclerosis and crural involvements Complete otosclerosis of the footplate may still be operable as long as the annulus of the footplate remains well defined and there is no crural involvement, this

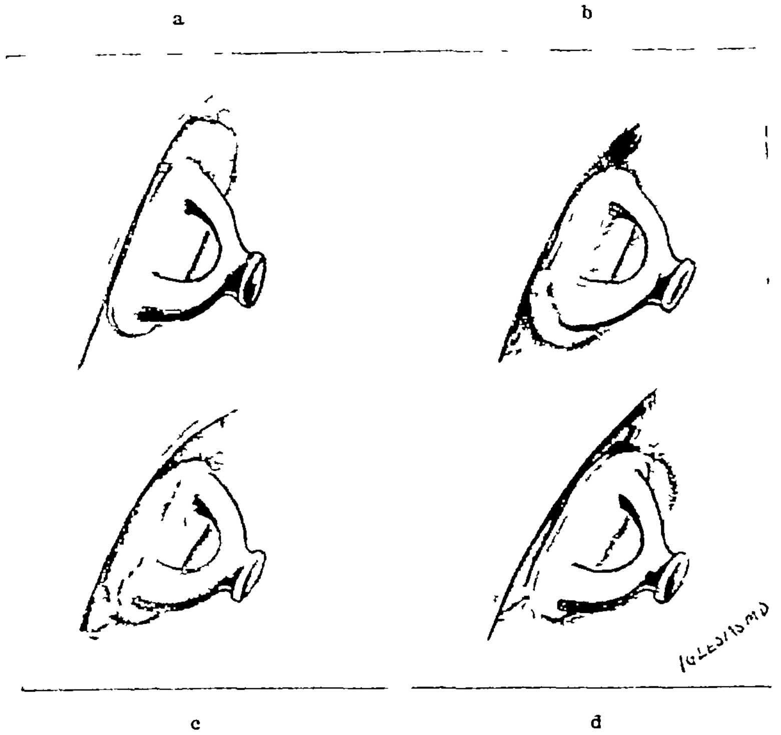

Fig 4 Footplate otosclerosis Circumscribed footplate otosclerosis is most favorable for stapes mobilization surgery The otosclerosis tends to remain at the level of the footplate when the footplate is superficial and the crura do not contact the margins of the oval window niche Anterior footplate (see Fig 4b) and superior marginal (see Fig 4c) otosclerosis are present occasionally Inferior marginal (see Fig 4d) otosclerosis is frequent, and is usually a continuation posteriorly of anterior footplate otosclerosis (see Chart II)

is found in thin, white otosclerosis (see Fig 6a) When the otosclerosis is thick enough to obliterate the annulus of the footplate the stapes becomes inoperable (see Fig 6b)

Otosclerosis may involve one or both crura, as previously stated, crural otosclerosis is most likely to occur in the deeply placed footplate with tilted crura Anterior crural otosclerosis (see Fig 5a) is favorable for mobilization surgery, but re-fixation is likely to occur unless an anterior-crurotomy is performed—Fowler[4] Posterior crural otosclerosis (see Fig 5b) has not been found as an isolated patholog-

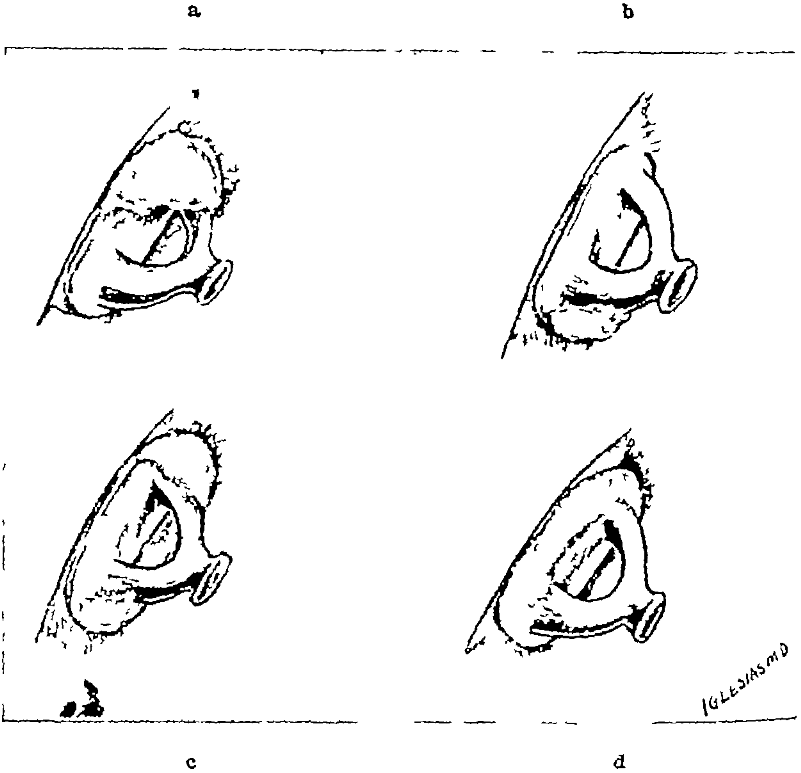

Fig 5 Crural otosclerosis Crural involvement by the otosclerotic process greatly alters the operability of the stapes Anterior crural (see Fig 5a) otosclerosis is frequent and is an indication for anterior crurotomy and posterior footplate mobilization Posterior crural (see Fig 5b) otosclerosis has not been found as an isolated entity Bi-crural otosclerosis is found with some frequency and is associated with inferior marginal (see Fig 5c) or superior marginal (see Fig 5d) otosclerosis in a deeply placed footplate

ical entity, but if it does, I should consider a posterior-crurotomy

Bi-crural otosclerosis has occurred in numerous instances, most frequently with inferior marginal otosclerosis (see Fig 5c), and occasionally in superior marginal otosclerosis (see Fig 5d) In each instance there has been re-fixation of the stapes after successful complete mobilization It is my present opinion that bi-crural otosclerosis is beyond the limits of present day mobilization surgery, and in the suitable candidate is a clear-cut indication for the fenestration operation In some instances the otosclerotic fixation has extended up the crura to involve the apex of the two crura and the neck

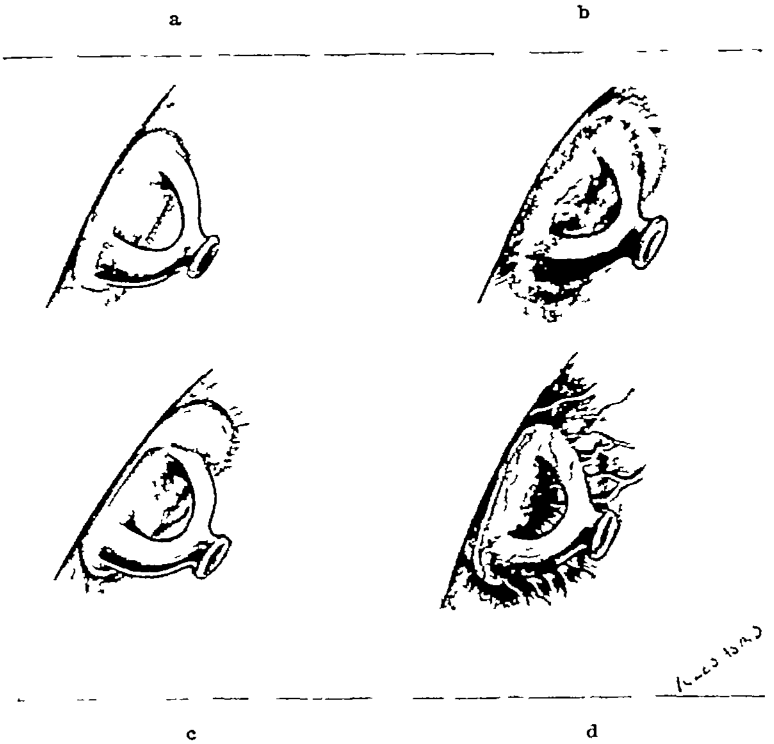

Fig 6 Character of otosclerosis. The thickness and the color (vascularity) of the otosclerosis alter the operability of the stapes Complete footplate otosclerosis may still be operable when thin the annulus is well defined and the crura are not involved (see Fig 6a) however when the otosclerosis of the complete footplate and oval window niche becomes thick enough to obliterate the annulus (see Fig 6b) of the footplate the stapes is then inoperable.

Circumscribed white avascular otosclerosis (see Fig 6c) is most favorable for stapes surgery while diffuse red vascular otosclerosis (see Fig 6d) will usually re-fix, even after complete mobilization.

of the stapes Such apical and cervical otosclerosis are beyond the limits of present day mobilization surgery

Bi-crural otosclerosis, with an area of normal or nearly normal footplate, may prove to be the type of pathology that will respond to mobilization or excavation of the footplate with or without replacing the crura (re-crural or de-crural)

Complete otosclerotic closure of the round window is a contra-indication to mobilization or fenestration surgery With a partial or almost complete closure of the round window the patient can still obtain maximum benefits from surgery, however, the long term prognosis is not favorable Round window closure has occurred independent of stapes fixation, however, in most instances there is associated unfavorable or inoperable pathology of the stapes (diffuse otosclerosis, see Fig 6d)

CHART III—PATHOLOGICAL VARIABLES

The otosclerosis may be thin or thick, white or red, depending upon the activity and vascularity Circumscribed thin white otosclerosis of the anterior footplate is most favorable for stapes surgery, while diffuse thick red vascular otosclerosis is inoperable

| Character of Otosclerosis | Operability |
|---|---|
| V Thickness of Otosclerosis of Stapes and Oval Window (see Fig 6a and b) | |
| 1 Very Thin | Favorable |
| 2 Thin | Favorable |
| 3 Moderately Thick | Unfavorable |
| 4 Thick | Inoperable |
| VI Color of Otosclerosis (see Fig 6c and d) | |
| 1 White | Favorable |
| 2 Nearly White | Favorable |
| 3 Pink | Unfavorable |
| 4 Red | Inoperable |

### *V Thickness of Oval Window Otosclerosis of the Stapes*

The thickness of the otosclerosis alters the operability of the stapes (see Charts III-V) Thin circumscribed otosclerosis is most favorable for mobilization surgery, while thick diffuse otosclerosis is the most unfavorable As previously stated, as long as the margin of the annulus of the footplate is not obliterated by the disease and the crura are free, the operability is reasonably favorable (see Fig 6a), however, when the otosclerosis thickens to obliterate the annulus or fill the oval window, the stapes becomes inoperable (see Fig 6b) This is most frequent in diffuse otosclerosis In such cases, there is no need to jeopardize inner ear function with excessive footplate surgery when the existing pathology is beyond the limits of stapes surgery, present or future

### *VI Color of Otosclerosis*

The operability of the stapes varies with the color of the otosclerosis (see Charts III-VI) White (avascular) otosclerosis (see Fig 6c) is most favorable for lasting results in mobilization surgery, while in red (vascular) otosclerosis (see Fig 6d) mobilization can be accomplished, but there is almost uniform re-fixation The vascularity and operability may vary from white, to off-white, to pink, to red Again, if on a pathological basis the prognosis is most unfavorable, it is absurd to persist in an operation where at best there will be a transient improvement, and where excessive surgery might result in cochlear damage

## THE AUDIOGRAM AND THE LOCATION OF THE OTOSCLEROSIS

Worthy of note is the effect of otosclerotic involvement upon the audiogram

Anterior footplate and anterior crural otosclerosis tend to present a flat or ascending air conduction audiogram with nearly normal bone conduction As the fixation of the footplate progresses the Carhart[5] notch develops It has long been taught that loss of high tones indicates complete footplate fixation I have seen a number of cases with flat audiograms and complete footplate fixation, but the flat audiogram persists only as long as good strong free crura are transmitting vibrations to the fixed footplate When the sides of both crura become fixed, and they are no longer capable of transmitting to the footplate, then there is loss of the high tones (2,000, 4,000 and 8,000), and progression of the Carhart notch, with diminution of the air bone gap at 2,000 This has occurred when crural fixation was associated with complete footplate fixation, but, of greater significance is the fact that this has occurred, in combined marginal and bi-crural otosclerosis when the opposite half of the footplate was a perfectly normal translucent blue, that is, incomplete footplate fixation but complete loss of crural transmission Subject to subsequent statistical study, it is my present clinical opinion that the audiogram tends to remain flat and speech discrimination good as long as strong free crura are transmitting vibrations to the footplate, even though the footplate itself is completely fixed dow the patient can still obtain maximum benefits from surgery, however, the long term prognosis is not favorable Round window closure has occurred independent of stapes fixation, however, in most instances there is associated unfavorable or inoperable pathology of the stapes (diffuse otosclerosis, see Fig 6d)

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This association of the type of otosclerotic involvement and the high tone loss does not apply to an independent nerve deafness—Farrior [6] For example, when there is an independent nerve loss for the high tones from one cause (acoustic trauma, presbycusis, etc ), and the patient has otosclerosis, causing the loss of low tones, the association of high tone loss with progression is not true This type of independent high tone loss does not indicate alteration in the operability of the stapes

### CHART IV —MISCELLANEOUS PATHOLOGY

Stapes surgery has revealed a never ending list of miscellaneous lesions which will produce or complicate an otosclerotic type of deafness This classification is presented for the accumulation of statistical data

VII —Mucous Membrane Webs
VIII —Fibrous Adhesions
IX —Abnormalities of Footplate
X.—Abnormalities of Anterior Crus
XI —Abnormalities of Posterior Crus
XII —Abnormalities of Stapedius
XIII —Abnormalities of Incus
XIV —Abnormalities of Malleus
XV —Systemic Diseases

The cases of combined oval and round window closure have been severely deaf, and audiometrically have shown only a little residual air conduction and bone conduction for the lower tone frequencies, however, such an audiogram does not always indicate round window closure

## MISCELLANEOUS PATHOLOGY

By clinical observation under the operating microscope we are discovering a never ending list of miscellaneous lesions (see Chart IV), which will simulate the otosclerotic type of deafness or will alter the operability of the stapes In the past our knowledge of the variables of otosclerosis has been limited to a relatively small number of autopsy specimens—Fowler,[3] Ruedi,[7] Guild,[8 9 10] Eggston and Wolfe,[11] Lindsey,[12] and others Today, with the operating microscope, and photographic slides of the surgical pathology, the opportunity to learn about the pathology and audiology of otosclerosis is greatly increased

As otologists learn the detail of the pathology of otosclerosis we add to this never ending list of miscellaneous pathological entities and learn the significance of minute variations in middle ear anatomy and pathology. Mucous membrane webs over and around the stapes are a frequent occurrence, and do not greatly alter the operability of the stapes. I used to destroy these mucous membrane webs to obtain greater visibility of the stapes, however, I believe this results in greater post-operative scar formation, and at present prefer to operate through or around these webs. Dense scar tissue does alter the operability of the stapes, the operability varying with the amount and location of the scar tissue, where possible, I remove or shunt these fibrous adhesions, but believe that adhesions tend to recur as they do elsewhere in the body.

CHART V.—PATHOLOGICAL COMBINATIONS

The operability of the stapes is determined by the combination of the anatomical and pathological variables. The following are in general the order of frequency of these combinations.

1. Anterior footplate.
2. Anterior footplate, anterior crural.
3. Anterior footplate, anterior crural, inferior marginal.
4. Anterior footplate, anterior crural, inferior marginal, posterior crural.
5. Anterior footplate, anterior crural, superior marginal.
6. Anterior footplate, anterior crural, superior marginal, posterior crural.
7. Complete footplate, thin.
8. Complete footplate, thick.

Schuknecht has reported a case of fixation of the stapedius tendon. Odess reports a case of malleable incus. All of us have seen fixed ossicles in congenital deformities, infections and in arthritis. I have one case with large blue footplate with apparent congenital absence of the annulus of the footplate. This list of miscellaneous pathology will never be complete, and all oddities should be reported. The list of miscellaneous pathology is presented as a basic classification, to which unusual cases can be added.

## ACCURATE DIAGNOSIS AND CLASSIFICATION

Any statistical reporting of results of mobilization surgery

This association of the type of otosclerotic involvement and the high tone loss does not apply to an independent nerve deafness—Farrior[6] For example, when there is an independent nerve loss for the high tones from one cause (acoustic trauma, presbycusis, etc ), and the patient has otosclerosis, causing the loss of low tones, the association of high tone loss with progression is not true This type of independent high tone loss does not indicate alteration in the operability of the stapes

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The 3-D photographs are taken from the position of the operator, sitting behind the patient looking into the middle ear The incus is the key anatomical landmark, the pathology will be described in relation to the incus first, anterior to the incus (around the anterior crus and footplate), and second, posterior to the incus from superior to inferior (left to right) For clarity of presentation all ears are presented as right ears

## OUTLINE OF ILLUSTRATIVE CASES

*Introductory Cases* Case 1—Ideal Pathology, Case 2—Inoperable Otosclerosis, Case 3—Bilateral Otosclerosis, Case 4—Fibrous Adhesions

*Anatomical Positions* Case 5—Downward Tilt, Case 6—Upward Tilt, Case 7—Upward Tilt with Fixation, Case 8—Fallopian Canal Otosclerosis

*Crural Otosclerosis* Case 9—Anterior Crural Otosclerosis, Case 10—Superior Bi-crural Otosclerosis, Case 11—Inferior Bi-crural Otosclerosis

*Character of Otosclerosis* Case 12—Pink Otosclerosis, Case 13—Thin complete footplate otosclerosis, Case 14—Thick complete footplate otosclerosis, Case 15—Inoperable Otosclerosis oval and round window

*Post-Mobilization Pathology* Case 16—Post-mobilization fibrous, Case 17—Probable technical mobilization failure, Case 18—Primary stapes failure from unfavorable pathology, Case 19—Primary stapes failure, inoperable thick footplate

*Fenestration Continuity* Case 20—Footplate mobilization attempted (thick footplate), Case 21—Unfavorable stapes pathology

## INTRODUCTORY CASES

Case 1 SR—282 F —Ideal Pathology

Diagnosis

1 Otosclerosis circumscribed anterior footplate (1/4) thin white favorable

should be based upon the type of anatomical development and the type of pathology present. Only by such a basic classification can we learn which operations, and which techniques, will give lasting results in individual pathological circumstances. This classification of the anatomy, pathology of otosclerosis and miscellaneous pathology is presented as we begin to define the operability of the stapes; degrees of involvement are outlined for coding statistics. The variables are many, and the operability is determined by the combinations of the anatomical and pathological variables (see Chart V). This classification should be changeable; other contributors should make suggestions and corrections, and the opinions on operability of the stapes will naturally vary from year to year as we learn new techniques and new limitations. Certainly the diagnosis "otosclerosis" alone is inadequate for study and future reference. The diagnosis should include a description of the anatomical and pathological findings, and should be complete as:

1. Otosclerosis, circumscribed, thin, white, anterior footplate, 3/4 blue, inferior marginal, favorable.

2. Stapes, fixed, deep, downward tilt.

3. Round window, normal, webs.

4. Hearing, flat audiogram, 45 db. loss, air-bone gap 35, good speech discrimination, good candidate.

## ILLUSTRATIVE CASES

This study is based upon a series of three-dimensional photographs of the surgical pathology of the stapes. More than 850 photographs have been taken in a series of 147 consecutive operations for otosclerosis. The experiences are based upon a series of 326 mobilizations and 724 fenestrations—a total of more than 1,000 operations. The pathology found in selected cases is herein described in detail to illustrate the effect of the variable pathology on the operability of the stapes.

With each illustrative case will be given, first, the detailed diagnosis; second, the description of the surgical pathology

*Comments*

In bilateral otosclerosis the anatomy and pathology of the stapes are similar in type, though they may vary in degree

In this minimal pathology mobilization was attempted by indirect pressure on the incus, however, when the posterior crus began to redden, indicating an impending fracture, a direct attack was made upon the anterior footplate and complete footplate mobilization obtained

Case 4 SR—254 Von V—Adhesions and Otosclerosis

Diagnosis

1 Otosclerosis, circumscribed, thin white anterior footplate with thick fibrous adhesions
2 Stapes fixed upright strong crura.
3 Round window normal

Description of 3 D Photograph

This is a favorable stapes complicated by white fibrous adhesions

A Anterior to the incus

1. Thin, white otosclerosis fixes the anterior margin of the foot plate.

P Posterior to the incus, from superior to inferior are

1 The normal Fallopian canal
2 An area of superficial blue footplate
3 The anterior portion of the footplate is covered by white fibrous adhesions, the posterior 1/2 of the footplate is normal blue
4 The posterior crus is strong and upright
5 The round window is normal

*Comments*

Fibrous adhesions limit the operability of the stapes

In this case with thin, white anterior footplate otosclerosis and anterior footplate adhesions there was prompt re-fixation of the stapes Subsequently, an anterior crurotomy and posterior footplate mobilization were performed, giving a lasting result

### ANATOMICAL POSITIONS

Case 5 SL—255-Y—Downward Tilt.

Diagnosis

1 Otosclerosis, circumscribed, white anterior footplate footplate 3/4 blue
2 Stapes deep footplate downward tilt of crura no posterior crural fixation unfavorable
3 Round window normal

2 Stapes, fixed, superficial upright
3 *Round window normal*

Description of 3 D Photograph (Fig 1)

A Anterior to the incus there is an area of thin white footplate otosclerosis, the otosclerosis does not involve the anterior crus

P Posterior to the incus, from superior to inferior, are

1 The normal Fallopian canal
2 The normal translucent easily seen superficial footplate of the stapes
3 The upright free strong posterior crus of the stapes
4 The stapedius tendon
5 The normal round window

*Comments*

This stapes, with limited pathological involvement of the footplate, was mobilized with the indirect approach by pressure on the incus The result was lasting

Case 2 SL—214-MM —Inoperable Diffuse Otosclerosis

Diagnosis

1 Otosclerosis, diffuse red footplate (3/4), bi crural inoperable
2 Stapes fixed, deep, downward tilt
3 Round window closing nearly complete

Description of 3 D Photograph (more than Fig 6d)

A. Anterior to the incus

1 Red vascular otosclerosis involves the entire anterior crus to the apex of the crura
2 The promontory is covered with red vascular otosclerosis

P Posterior to the incus, from superior to inferior are

1 The normal Fallopian canal
2 A very deep footplate of the stapes, almost invisible
3 There is a downward tilt of the posterior crus with posterior crural otosclerosis
4 There is almost complete closure of the round window

*Comments*

Mobilization was easily accomplished by pressure on the incus, however, in thick, red bi-crural otosclerosis of a deep stapes with downward tilt of the crura, the mobilization was of transient value In almost complete round window closure in active otosclerosis, fenestration would be of transient value, and I have advised against fenestration surgery because of the emotional instability of the patient

Case 3 SL—283 F —Bilateral Otosclerosis

Diagnosis and description

This is the left ear of Case 1 the diagnosis anatomy and pathology are almost identical (see Fig 1)

*Comments*

In bilateral otosclerosis the anatomy and pathology of the stapes are similar in type, though they may vary in degree

In this minimal pathology mobilization was attempted by indirect pressure on the incus, however, when the posterior crus began to redden, indicating an impending fracture, a direct attack was made upon the anterior footplate and complete footplate mobilization obtained

Case 4 SR—254 Von V—Adhesions and Otosclerosis

Diagnosis

1 Otosclerosis circumscribed, thin, white anterior footplate with thick fibrous adhesions
2 Stapes fixed, upright strong crura.
3 Round window normal

Description of 3 D Photograph

This is a favorable stapes, complicated by white fibrous adhesions

A. Anterior to the incus
  1. Thin, white otosclerosis fixes the anterior margin of the foot plate

P Posterior to the incus from superior to inferior are
  1 The normal Fallopian canal.
  2 An area of superficial blue footplate
  3 The anterior portion of the footplate is covered by white fibrous adhesions the posterior 1/2 of the footplate is normal blue.
  4 The posterior crus is strong and upright.
  5 The round window is normal

*Comments*

Fibrous adhesions limit the operability of the stapes

In this case with thin, white anterior footplate otosclerosis and anterior footplate adhesions there was prompt re-fixation of the stapes Subsequently, an anterior cruriotomy and posterior footplate mobilization were performed, giving a lasting result

## ANATOMICAL POSITIONS

Case 5 SL—255-N—Downward Tilt.

Diagnosis

1 Otosclerosis circumscribed, white anterior footplate footplate 3/4 blue
2 Stapes deep footplate downward tilt of crura, no posterior crural fixation unfavorable
3 Round window normal

This is an operable but unfavorable stapes with a deep footplate and *downward tilt of the crura.*

Description of 3 D Photograph (see Fig 2)

A Anterior to the incus

1 There is circumscribed anterior footplate otosclerosis

P Posterior to the incus, from superior to inferior, are

1 The normal Fallopian canal

2 The normal blue translucent footplate deeply placed in the oval window niche

3 The downward tilt of the posterior crus brings it into contact with the inferior lip of the oval window niche This approximation makes the posterior crus susceptible to otosclerotic fixation by the adjacent otosclerotic involvement (Similar to Fig 2 with otosclerosis extending posteriorly adjacent to but not fixing posterior crus)

*Comments*

At present this patient has a good result which should last unless there is otosclerotic involvement of the posterior crus

Case 6 SR—213 A —Upward Tilt.

Diagnosis

1 Otosclerosis, circumscribed, thin, white, anterior footplate, foot plate not seen

2 Stapes fixed very deep, uptilt of crura, contacting Fallopian canal

3 Normal round window

This is an operable but anatomically unfavorable stapes

Description of 3 D Photograph

P Posterior to the incus, from left to right are

1 The normal Fallopian canal

2 *The footplate of the stapes is not visible but in a narrow deep niche*

3 There is marked upward tilt of the crura so that the neck of the stapes is in contact with the Fallopian canal (similar to Fig 3 with no otosclerosis on Fallopian canal)

4 The round window is normal

*Comments*

This stapes mobilized easily with pressure on the incus The deep footplate with upward tilt of the crura makes the prognosis guarded in this now successful mobilization (see next case) Although anatomically unfavorable, the result has lasted because there was no crural involvement

Case 7 SR—269 L —Upward Tilt Footplate Mobilization and Re-Application of Crura.

Diagnosis

1 Otosclerosis diffuse bi-crural and cervical, with fixation to Fallopian canal and obliteration of 1/2 of footplate

2 Stapes fixed, very deep inaccessible footplate upward tilt.
3 Round window patent but marginal otosclerosis
This is an extensive unfavorable otosclerosis

Description of 3 D Photograph

A Anterior to the incus there is
  1 Red otosclerotic involvement of the promontory
P Posterior to the incus from superior to inferior are
  1 Otosclerosis of the Fallopian canal
  2 Otosclerotic fixation between the Fallopian canal and the neck of the stapes (Cervical otosclerosis—more than Fig 3)
  3 Red vascular otosclerosis of the promontory
  4 Normal round window
  5 Footplate of the stapes is so deep that it is invisible, the resultant upward tilt of the crura predisposed toward the otosclerotic fixation of the neck.

*Comments*

The red vascular otosclerotic fixation between the Fallopian canal and the neck of this deeply placed stapes, with upward tilt and fixation of both crura, makes this an inoperable stapes by currently accepted mobilization techniques As this 54-year-old male presented 85 db loss and was not suitable for fenestration surgery, the footplate of the stapes was investigated The crura of the stapes were fractured and retracted downward to expose the footplate (The anterior footplate, anterior crural, inferior marginal and posterior crural otosclerosis were more extensive than Fig 5c) Approximately one-half of the footplate was normal blue This central portion of the footplate was mobilized with the chisel The remnant of the stapes still attached to the incus was swung back into position over the mobile central portion of the footplate This operation was done on September 10, 1957 On February 7, 1958 (5 months post-operative), the patient still poossessed a 42 db hearing improvement to the 43 db hearing level

Such bi-crural otosclerosis is beyond the limits of accepted methods of mobilization surgery, and as previously stated, required some type of oval window surgery with or without the application of prosthetic crura

Shea advocates excavation of the oval window and the application of a vein graft and prosthetic crura or re-application of a uni-pod stapes

This is an operable but unfavorable stapes with a deep footplate and downward tilt of the crura

Description of 3 D Photograph (see Fig 2)

A Anterior to the incus

1 There is circumscribed anterior footplate otosclerosis

P Posterior to the incus, from superior to inferior, are

1 The normal Fallopian canal
2 The normal blue translucent footplate deeply placed in the oval window niche
3 The downward tilt of the posterior crus brings it into contact with the inferior lip of the oval window niche This approximation makes the posterior crus susceptible to otosclerotic fixation by the adjacent otosclerotic involvement (Similar to Fig 2 with otosclerosis extending posteriorly adjacent to but not fixing posterior crus)

*Comments*

At present this patient has a good result which should last unless there is otosclerotic involvement of the posterior crus

Case 6 SR—213 A —Upward Tilt

Diagnosis

1 Otosclerosis, circumscribed, thin, white, anterior footplate, foot plate not seen
2 Stapes fixed, very deep, uptilt of crura, contacting Fallopian canal
3 Normal round window

This is an operable but anatomically unfavorable stapes

Description of 3 D Photograph

P Posterior to the incus, from left to right are

1 The normal Fallopian canal
2 The footplate of the stapes is not visible but in a narrow deep niche
3 There is marked upward tilt of the crura so that the neck of the stapes is in contact with the Fallopian canal (similar to Fig 3 with no otosclerosis on Fallopian canal)
4 The round window is normal

*Comments*

This stapes mobilized easily with pressure on the incus The deep footplate with upward tilt of the crura makes the prognosis guarded in this now successful mobilization (see next case) Although anatomically unfavorable, the result has lasted because there was no crural involvement

Case 7 SR—269 L—Upward Tilt Footplate Mobilization and Re-Application of Crura.

Diagnosis

1 Otosclerosis diffuse, bi crural and cervical with fixation to Fallopian canal and obliteration of 1/2 of footplate

*Comments*

In thick, white anterior footplate and anterior crural otosclerosis, the prognosis is favorable, with Fowler's anterior-cruriotomy and complete posterior footplate mobilization of the stapes

Case 10 SR—283 SS—Superior Bi-Crural Otosclerosis

Diagnosis

1 Otosclerosis, circumscribed red, thick, superior marginal bi-crural, inferior 1/2 of footplate blue
2 Stapes fixed footplate deep crura upright.
3 Round window normal

Description of 3 D Photograph

P Posterior to the incus, from superior to inferior are

1 The normal Fallopian canal
2 Red vascular otosclerosis along the entire superior margin of the footplate replacing the annulus, fixing the length of the footplate and fixing the superior edge of the anterior and posterior crus and filling the superior 1/2 of the oval window niche (Fig 5d)
3 The inferior half of the footplate is normal translucent blue
4 The inferior margin of the annulus is normal
5 The round window is normal

*Comments*

It is easy enough to mobilize such a stapes, but there is usually prompt re-fixation with thick, red superior marginal, bi-crural otosclerosis Audiometrically, this bi-crural otosclerosis shows a sloping air-conduction curve with loss of high tones

Because of the marked narrowing of this deep oval window niche, and the fact that this 22-year-old female is suitable for fenestration surgery, I have advised against further oval window surgery, and have encouraged the patient to have a fenestration operation

Case 11 SL—225-MH—Inferior Bi Crural Otosclerosis

Diagnosis

1 Otosclerosis circumscribed white anterior footplate inferior marginal bi-crural 3/4 of footplate blue unfavorable
2 Stapes fixed deep footplate downward tilt of crura
3 Round window normal

Description of 3 D Photograph

A. Anterior to the incus there is

1 A wide area of white anterior footplate and anterior crural otosclerosis

As in this case, at the present time, I feel that such oval window surgery should be reserved for those cases which are no longer suitable for the fenestration operation

Case 8 SR—308—Fallopian Canal Otosclerosis

Diagnosis

1 Otosclerosis circumscribed, red, Fallopian canal to anterior crus, footplate normal
2 Stapes fixed, upright, deep
3 Round window normal

Description of 3 D Photograph

P Posterior to the incus from left to right are

1 The Fallopian canal
2 On the inferior border of the Fallopian canal there is a red prominence of otosclerotic bone projecting downward to fix the superior surface of mid portion of the anterior crus (Similar to Fig 3 but not localized to anterior crus)
3 Deep to the bony prominence there is a normal blue, deeply placed footplate
4 The posterior crus and stapedius tendon are not involved
5 The chorda tympani nerve and round window are normal

*Comments*

The superior otosclerotic fixation external to a normal footplate is rare Because of the anterior crural fixation an anterior crurotomy was attempted, however, in the process the stapes was completely mobilized, making crurotomy impracticable At present, the hearing is good

## CRURAL OTOSCLEROSIS

Case 9 SR—272—Anterior Crural Otosclerosis

Diagnosis

1 Otosclerosis, circumscribed, thick pink anterior crural, footplate 3/4 blue favorable
2 Stapes fixed, moderate superficial upright, strong crura.
3 Round window normal

Description of 3 D Photograph (Less than Fig 4a)

A Anterior to the incus

1 Thick white otosclerosis surrounds the anterior footplate and anterior crus

P Posterior to the incus from superior to inferior are

1 The normal Fallopian canal
2 A moderately deep uninvolved area of the footplate of the stapes
3 A strong free, upright posterior crus
4 A normal round window

3 Upright crura which do not touch the margins of the oval window (similar to Fig 3 without contact)
4 Pink otosclerosis extending over the promontory (similar but less than 6d)
5 Patent round window with marginal round window otosclerosis

*Comments*

In general re-fixation is prompt in such pink otosclerosis however, this case has maintained hearing improvement This lasting improvement probably occurred because the crura of the stapes were upright, and were not involved in the otosclerotic process In stapes surgery it is the possible combinations of favorable and unfavorable anatomy and pathology which determine operability (see Chart V)

Case 13 SL—247 A —Complete Thin Footplate Otosclerosis

Diagnosis

1. Otosclerosis circumscribed thin white, complete footplate annulus discernable
2. Stapes fixed superficial crura upright, free
3. Round window normal.

Description of 3 D Photograph

P Posterior to the incus from left to right, are

1. The normal Fallopian canal
2. The footplate is superficial and completely replaced by the otosclerotic process The margins of the footplate are thin so that the annular margin of the footplate is visible superiorly and inferiorly (see Fig 6a)
3. The crura are strong upright and do not contact the margins of the oval window
4. The round window is normal

*Comments*

This appeared to be an inoperable footplate, however, with manipulation at the annulus with the chisel, complete footplate mobilization was obtained, and the patient has a lasting hearing improvement

Six months post-operatively, this patient states that her hearing has remained good, and the audiogram shows a 30 db hearing improvement to the 25 db level

Case 14 SL-237-S —Thick Complete Footplate Otosclerosis

Diagnosis

1. Otosclerosis diffuse red thick, complete footplate with filling of the oval window niche
2. Stapes fixed deep footplate crura free

P Posterior to the incus, from superior to inferior, are
  1 The normal Fallopian canal
  2 An area of normal blue footplate deeply placed in a narrow niche
  3 The normal superior and inferior margins of the footplate
  4 The downward tilt of the crura brings the crura into contact with the inferior lip of the oval window there is white otosclerotic fixation of the inferior border of the posterior crus (see Fig 5c)
  5 The round window is normal

### *Comments*

This bi-crural fixation of the deeply placed stapes with downward tilt of the crura is, to me, beyond the limits of our present day mobilization surgery In this case, and others, re-fixation has been prompt This is the type of case which might respond to mobilization of the footplate combined with an anterior and posterior crurotomy, and either the insertion of some type of non-osteogenic prosthetic crura, or a Type IV tympanoplasty As the case is clinically suitable, I have advised a fenestration operation

## CHARACTER OF OTOSCLEROSIS—COLOR AND THICKNESS

The color of the otosclerosis is dependent upon the vascularity and the activity of the otosclerotic process, the circumscribed white, inactive otosclerosis is difficult to mobilize, but does not tend to re-fix, while the red vascular otosclerosis is easy to mobilize but tends toward prompt re-fixation

White, nearly white, and red otosclerosis has been illustrated by previous cases

Case 12 SL—263 H —Diffuse Pink Otosclerosis

Diagnosis
  1 Otosclerosis, diffuse, pink anterior footplate unfavorable
  2 Stapes fixed deep, upright, crura not fixed
  3 Round window, patent, marginal otosclerosis

Description of 3 D Photograph

A Anterior to the incus
  1 There is pink otosclerosis fixing the anterior footplate and extending over the promontory

P Posterior to the incus from superior to inferior, are
  1 Pink otosclerosis involving the Fallopian canal
  2 A deeply placed almost invisible footplate

3 Upright crura which do not touch the margins of the oval window (similar to Fig 3 without contact)
4 Pink otosclerosis extending over the promontory (similar but less than 6d)
5 Patent round window with marginal round window otosclerosis

*Comments*

In general re-fixation is prompt in such pink otosclerosis however, this case has maintained hearing improvement This lasting improvement probably occurred because the crura of the stapes were upright, and were not involved in the otosclerotic process In stapes surgery it is the possible combinations of favorable and unfavorable anatomy and pathology which determine operability (see Chart V)

Case 13 SL—247 A —Complete Thin Footplate Otosclerosis

Diagnosis

1 Otosclerosis circumscribed thin white complete footplate annulus discernable
2 Stapes fixed superficial crura upright, free
3 Round window normal

Description of 3 D Photograph

P Posterior to the incus from left to right are

1 The normal Fallopian canal
2 The footplate is superficial and completely replaced by the otosclerotic process The margins of the footplate are thin so that the annular margin of the footplate is visible superiorly and inferiorly (see Fig 6a)
3 The crura are strong upright and do not contact the margins of the oval window
4 The round window is normal

*Comments*

This appeared to be an inoperable footplate, however, with manipulation at the annulus with the chisel, complete footplate mobilization was obtained, and the patient has a lasting hearing improvement

Six months post-operatively, this patient states that her hearing has remained good, and the audiogram shows a 30 db hearing improvement to the 25 db level

Case 14 SL-237 S —Thick Complete Footplate Otosclerosis

Diagnosis

1 Otosclerosis, diffuse red thick, complete footplate with filling of the oval window niche
2 Stapes fixed deep footplate crura free

P Posterior to the incus, from superior to inferior, are
  1 The normal Fallopian canal
  2 An area of normal blue footplate deeply placed in a narrow niche
  3 The normal superior and inferior margins of the footplate.
  4 The downward tilt of the crura brings the crura into contact with the inferior lip of the oval window there is white otosclerotic fixation of the inferior border of the posterior crus (see Fig 5c)
  5 The round window is normal

*Comments*

This bi-crural fixation of the deeply placed stapes with downward tilt of the crura is, to me, beyond the limits of our present day mobilization surgery In this case, and others, re-fixation has been prompt This is the type of case which might respond to mobilization of the footplate combined with an anterior and posterior crurotomy, and either the insertion of some type of non-osteogenic prosthetic crura, or a Type IV tympanoplasty As the case is clinically suitable, I have advised a fenestration operation

## CHARACTER OF OTOSCLEROSIS—COLOR AND THICKNESS

The color of the otosclerosis is dependent upon the vascularity and the activity of the otosclerotic process, the circumscribed white, inactive otosclerosis is difficult to mobilize, but does not tend to re-fix, while the red vascular otosclerosis is easy to mobilize but tends toward prompt re-fixation

White, nearly white, and red otosclerosis has been illustrated by previous cases

Case 12 SL—263 H—Diffuse Pink Otosclerosis

Diagnosis
  1 Otosclerosis diffuse pink anterior footplate, unfavorable
  2 Stapes fixed deep upright crura not fixed
  3 Round window, patent, marginal otosclerosis

Description of 3 D Photograph

A Anterior to the incus
  1 There is pink otosclerosis fixing the anterior footplate and extending over the promontory

P Posterior to the incus, from superior to inferior, are
  1 Pink otosclerosis involving the Fallopian canal
  2 A deeply placed almost invisible footplate

dow closure Had the oval window not been completely closed, I would have proceeded with the fenestration operation

## POST-MOBILIZATION PATHOLOGY

Re-fixation of the stapes, or primary mobilization failures, may result from either technical or pathological causes Re-fixation of the stapes may result from inadequate surgery, but more frequently re-fixation occurs in unfavorable or inoperable anatomical and pathological circumstances This is the cause for re-fixation after complete mobilization Inadequate surgery includes incomplete mobilization, and failure to do an anterior-crurotomy in anterior crural otosclerosis

Primary mobilization failures may result from inexpert surgery, or improper surgical attack, more frequently, primary failures occur to the reasonably competent surgeon, because the pathology present was beyond the limits of stapes mobilization surgery A primary mobilization failure of inexpert surgery may convert a thoroughly operable stapes into an unfavorable or inoperable stapes

Re-operation on the stapes is rarely indicated because of probable primary unfavorable pathology and secondary scar formation Re-operation on the stapes is indicated only when the primary pathology and anatomy were found to be favorable Re-operation on the stapes should never be performed as a "solo" operation, for too often the re-operated stapes is found to be inoperable, therefore, in re-operation of the stapes one should be prepared to do a "fenestration in continuity" should the stapes prove to be pathologically inoperable

Case 16 SR—65-FR —713 EF

Diagnosis

1. Post mobilization fibrosis severe
2. Otosclerosis circumscribed anterior footplate anterior crural.
3. Stapes fixed deep footplate downward tilt
4. Round window normal.

Description of 3-D Photograph

This is a post-operative mobilization primary failure in which we are performing a fenestration operation and have exposed the entire incus

3 Round window normal

Description of 3 D Photograph

P Posterior to the incus, from superior to inferior, are

1 A normal Fallopian canal

2 A deeply placed footplate completely covered with thick, red, vascular otosclerosis which fills the oval window niche to apex of the crura of the stapes (see Fig 6b)

3 The round window is normal

*Comments*

Thick, red, complete footplate otosclerosis is inoperable and is a pathological indication for the fenestration operation I do not believe that oval window surgery will ever be applicable when the otosclerosis is so thick that the margins of the footplate are obliterated, and there is no remaining normal footplate

When exploration revealed the above described pathology, the operation was discontinued and a fenestration advised It is not necessary to fracture the crura, or to drive a chisel into the footplate, to know that mobilization would be a failure

Case 15 FL-718 B —Inoperable Otosclerosis, Oval and Round Window

Diagnosis

1 Otosclerosis, diffuse, red, anterior footplate inferior marginal, bi-crural, promontory, oval window

2 Stapes fixed, deep footplate, downward tilt

3 Round window, complete closure

Description of 3 D Photograph

P Posterior to the incus from superior to inferior, are

1 The normal Fallopian canal

2 A very deep, almost occluded footplate of the stapes

3 Downward tilt of the crura of the stapes, with complete otosclerotic fixation of one-half of the posterior crus (worse than Fig 6d with complete round window closure)

4 Red, vascular, otosclerosis of the promontory

5 Complete slit like closure of the round window

*Comments*

A primary fenestration was advised because of the positive Schwartze sign, but surgery was discontinued when exploration revealed the complete round window closure A fenestration may be of value if even a fraction of the round window is patent A hearing aid is indicated in complete round winstapes surgery in the first ear, I advise a fenestration on this ear before exploring the stapes on the opposite ear If the pathology was favorable in the first ear and the mobilization was a failure for technical reasons, a mobilization is performed on the opposite ear

Case 18 SL—276-FL—721-MD—Unfavorable Stapes

Diagnosis

1 P O stapes primary failure
2 Otosclerosis circumscribed anterior footplate anterior crural, inferior marginal posterior footplate, footplate 1/5 blue
3 Stapes, footplate deep, crura downward tilt fractured bound with adhesion
4 Round window normal

Description of 3 D Photograph

1 The incus scar tissue and crura of the stapes have been removed, exposing the oval window niche and footplate, from superior to inferior are
   1 The ampulla of the horizontal canal
   2 The Fallopian canal
   3 The deeply placed footplate of the stapes showing anterior and posterior footplate otosclerosis involving the stumps of the crura. The circumscribed white otosclerosis extends onto the promontory for about 1 mm (more than Fig 5c)

*Comments*

The stapes mobilization was a primary failure because of the crural and footplate otosclerosis Because of the small central area of blue footplate (1/5) some might advise excavation of the oval window and the application of prosthetic crura As a secondary operation, in a suitable candidate, I prefer the more reliable and predictable fenestration

Some surgeons justify multiple stapes operations on the patient's temporary objections to a fenestration Unless the secondary surgical procedure is reasonably predictable, I advise a hearing aid

Case 19 SL—99 FL—720-EK.—Inoperable Footplate

Diagnosis

1 P O stapes primary failure
2 Otosclerosis diffuse thick pink, complete footplate annulus obliterated crura atrophic
3 Stapes fixed superficial crura upright weak no fibrosis
4 Round window normal

Descroption of 3 D Photograph

1 A fenestration is being performed the incus has been removed from superior and inferior are

P Posterior to the incus, from superior to inferior, are
1 The Fallopian canal covered with scar tissue
2 Firm fibrous adhesions occlude the view of the deep footplate of the stapes and bind the stapes and stapedius tendon to the Fallopian canal and incus to the chorda tympani nerve tympani membrane and promontory

*Comments*

These fibrous adhesions of a deeply placed stapes, with downward tilt of the crura, make this an inoperable stapes and is a pathological indication for the fenestration operation

Case 17 S—67 F —715 A—Probable Technical Failure

Diagnosis
1 P O mobilization, re-fixation
2 Otosclerosis anterior footplate anterior crural, inferior marginal firm fibrous adhesions
3 Stapes fixed, deep, downward tilt.

Description of 3 D Photograph
P The incus has been dislocated from superior to inferior are
1 The ampulla of the horizontal canal
2 The Fallopian canal
3 The deeply placed footplate
4 Downward tilt of the posterior and inferior crus of the stapes otosclerosis fixing 1/2 of the anterior crus (see Fig 5a)
5 Fibrous adhesions fixing the stapes

*Comments*

This re-fixation of the stapes is probably a technical failure, for the patient has a good mobilization on the opposite ear, and in bilateral otosclerosis the pathology in the two ears is similar Anterior crurotomy may have prevented re-fixation In the opposite ear, the patient has maintained a 30 db hearing improvement to the 15 db level for 18 months In the operated ear under discussion the patient obtained a 25 db gain to the 30 db level with prompt loss of the gain As the secondary anatomy and pathology were unfavorable, a fenestration was performed yielding a 35 db gain to the 20 db level

In cases that have had stapes mobilization on both ears, if they have obtained one good result they are anxious to have a fenestration on the opposite ear, however, if both mobilizations have been a failure, they are reluctant to try any further surgery If the pathology is found to be unfavorable for

A fenestration is performed in continuity when the pathology is found to be beyond the limits of mobilization surgery The decision to perform a fenestration in continuity is based, not upon the blind audiometric failure, but upon the microscopic fact that the footplate is not mobile, and that the pathology is beyond the limits of stapes surgery

Case 21 FR—717 BS—Unfavorable Stapes

Diagnosis

1 Otosclerosis white circumscribed anterior footplate anterior crural inferior marginal posterior crural unfavorable
2 Stapes fixed deep downward tilt.
3 Round window normal.

Description of 3 D Photograph

A. The incus has been disarticulated, from superior to inferior are

1 The ampulla of the horizontal canal
2 The normal Fallopian canal
3 The deeply placed footplate of the stapes
4 There is a downward tilt of both crura white otosclerosis is seen to involve one-third of the anterior crus extend along the entire inferior margin of the footplate and involve the posterior crus (see Fig 5c)

*Comments*

When exploratory tympanotomy revealed this unfavorable pathology we proceeded with a "fenestration in continuity" without attempting mobilization The patient and the operating staff had been previously prepared, because of the sloping air-conduction audiogram with the disproportionate loss of high tones It would have been easy enough to mobilize this stapes, but in my present clinical opinion, the result would have been temporary, because of the bi-crural otosclerosis

Some surgeons advise that a stapes mobilization should always be tried first. A thesis of this study is that this trial and failure approach should be replaced by sound surgical judgment, based upon the clinical interpretation of the existing pathological circumstances

## CLINICAL COMMENTS

1 Stapes mobilization is the operation of choice in early and moderate circumscribed otosclerosis

1. The ampulla of the horizontal canal
2. The Fallopian canal
3. The footplate of the stapes is completely replaced by thick, pink, otosclerosis with obliteration of the annulus, there is no scar formation
4. The crura are atrophic
5. The round window is normal.

*Comments*

At the primary mobilization the crura of this inoperable stapes were fractured This thick footplate is beyond the operable limits of any known type of oval window surgery The fenestration was performed with a 26 db gain to the 22 db level

### FENESTRATION IN CONTINUITY

Case 20 FR—710 H —Inoperable Stapes

Diagnosis

1. Otosclerosis, circumscribed, complete footplate, white, flat, 1+ thick, annulus upright, strong
2. Stapes fixed, superficial footplate, crura upright, strong
3. Normal round window

Description of 3 D Photograph

P Posterior to the incus from superior to inferior are

1. The normal Fallopian canal
2. The footplate is broad, white, superficial, with the annulus almost obliterated (between Fig 6a and b)
3. The posterior crus is strong and upright
4. The round window is normal

*Comments*

Because of the severity of the deafness (80 db ), a fenestration was advised, anticipating an inoperable stapes When the exploratory tympanotomy revealed the anatomically favorable strong upright crura, and the anatomically favorable superficial footplate with white otosclerosis, efforts were made to mobilize the footplate, even though there was complete footplate otosclerosis with beginning obliterations at the annulus The chisel was used completely around the annulus of the footplate, but the footplate could not be mobilized A fenestration was performed in continuity, with resultant 37 db gain

In other instances, I have prepared for a fenestration and done a mobilization when the stapes proved to be operable

*11* Complete otosclerosis of the footplate may still present a flat audiogram if there is no crural fixation, at least until the otosclerosis becomes too thick or the crura too weak to transmit sound

*12* Bi-crural otosclerosis with round window closure is indicated clinically by the very severe associated "nerve" loss

### RE-FIXATION AND SECONDARY SURGERY

*13* Re-fixation of the stapes may result from inadequate surgery

*14* Most instances of re-fixation of the completely mobilized stapes result from unfavorable surgical anatomy and surgical pathology

*15* Re-operation on the stapes is indicated only in the presence of the most favorable anatomy and pathology, and primary incomplete mobilization

*16* Re-operation on the stapes is contra-indicated in unfavorable anatomy and pathology, unfavorability includes both the primary otosclerosis and the secondary post-mobilization cicatrization

*17* At the present time, in clinically suitable cases, I favor the fenestration operation over anterior and posterior cruotomy, and mobilization of the footplate alone or excavation of the footplate and the application of prosthetic crura

*18* Many stapedial footplates are so involved that they cannot be mobilized or excavated, and are an unequivocal indication for the fenestration operation in clinically suitable cases

*19* Adequate exposure and adequate magnification are advocated to

1. Give maximum opportunity for varied surgical attack on the variable anatomy and pathology of the stapes
2. To determine the pathological limitations of the stapes surgery
3. To determine the pathological indication for fenestration surgery

*2* In bilateral otosclerosis the anatomy and pathology of the stapes are similar in type, though they may vary in degree

*3* If the stapes mobilization on the first ear reveals favorable surgical pathology and favorable surgical anatomy, a mobilization is advised on the opposite ear

*4* If the stapes mobilization has been primarily successful in the presence of unfavorable pathology, the patient is advised of these findings and that he will probably need a fenestration While the hearing is still good and the morale high, he is given a tentative date for the subsequent fenestration (interval about three months)

*5* (a) If the first stapes mobilization was a failure, the surgical pathology is unknown, and the operated ear is the poorer ear, a fenestration operation is advised on this ear (see secondary mobilization surgery)

(b) If at the time of the fenestration, examination reveals that the stapes was primarily operable, subsequently a stapes mobilization is performed on the opposite ear

*6* If the first stapes mobilization is a failure, the surgical pathology unknown, and the unoperated ear is the poorer ear, an exploratory tympanotomy is done on the unoperated ear and a mobilization or fenestration done, depending upon the pathological findings

*7* A positive Schwartze sign is probably a contra-indication to mobilization surgery, certainly it is a contra-indication to a "solo" mobilization

*8* In mobilization surgery crural otosclerosis is an indication for crurotomy to prevent re-fixation

*9* Bi-crural otosclerosis is probably a contra-indication to mobilization surgery, although in the severely deaf some improvement may result from anterior and posterior crurotomy and mobilization or excavation of an operable footplate, with or without the application of prosthetic crura

*10* Bi-crural otosclerosis is believed to be indicated clinically by otosclerotic loss of the high tones

## SUMMARY

*1* There are specific pathological indications for stapes surgery and there are specific pathological indications for fenestration surgery

*2* The operability of the stapes is based upon the type of anatomical development, the degrees of pathological involvement and the possible combinations of these variables

*3* There is often a direct correlation between the severity of the deafness, the pathological involvement and the operability of the stapes

*4* A basic classification of the anatomy and pathology is presented, degrees of involvement are presented for coding of anatomy and pathology and the classification of surgical results

*5* Any classification of results of stapes surgery should be based upon the type of anatomical development, and the type of pathological involvement In this way we will ultimately define the operability of the stapes

*6* Current opinions are expressed relative to the favorable, unfavorable, and inoperable stapes, based upon the anatomical development and pathological involvement

*7* The variable operability of the stapes is described in a series of illustrative cases

*8* The stapes mobilization operation is a reliable surgical procedure in favorable anatomical and pathological circumstances

*9* Stapes surgery has enough advantages to make it worthy of a trial in less favorable anatomical and pathological circumstances

*10* The fenestration operation is indicated when the anatomical development and pathological involvement are beyond the limits of reasonably predictable stapes surgery

*11.* If the stapes surgeon strives to obtain the maximum percentage of primary mobilization results in all types of

pathological involvement, he will jeopardize the functions of many inner ears with little gain in the percentage of cases with lasting hearing improvement We are learning the limits of successful mobilization surgery

*12* Unfavorable pathology is the most frequent cause for re-fixation after complete stapes mobilization

*13* Incomplete stapes mobilization or inexpert surgery may convert an operable stapes into an inoperable stapes

*14* Re-operation of the stapes is rarely indicated unless the first surgery revealed favorable pathology and the mobilization was incomplete

*15* True, the inoperability of the stapes cannot be determined without microscopic inspection of the pathology, but inoperability may be suspected if there is a positive Schwartze, a high tone loss, or if the patient is very hard of hearing (50 db or more)

*16* The inoperable stapes is a firm pathological indication for the fenestration operation in a clinically suitable case Inoperability of the stapes may result from extensive otosclerosis, vascular otosclerosis, post-mobilization cicatrization, adhesive processes, or a combination of these, with unfavorable anatomical development

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## SUMMARY

*1* There are specific pathological indications for stapes surgery and there are specific pathological indications for fenestration surgery

*2* The operability of the stapes is based upon the type of anatomical development, the degrees of pathological involvement and the possible combinations of these variables

*3* There is often a direct correlation between the severity of the deafness, the pathological involvement and the operability of the stapes

*4* A basic classification of the anatomy and pathology is presented, degrees of involvement are presented for coding of anatomy and pathology and the classification of surgical results

*5* Any classification of results of stapes surgery should be based upon the type of anatomical development, and the type of pathological involvement In this way we will ultimately define the operability of the stapes

*6* Current opinions are expressed relative to the favorable, unfavorable, and inoperable stapes, based upon the anatomical development and pathological involvement

*7* The variable operability of the stapes is described in a series of illustrative cases

*8* The stapes mobilization operation is a reliable surgical procedure in favorable anatomical and pathological circumstances

*9* Stapes surgery has enough advantages to make it worthy of a trial in less favorable anatomical and pathological circumstances

*10* The fenestration operation is indicated when the anatomical development and pathological involvement are beyond the limits of reasonably predictable stapes surgery

*11.* If the stapes surgeon strives to obtain the maximum percentage of primary mobilization results in all types of

# SUPRAGLOTTIC SUBTOTAL LARYNGECTOMY AND RADICAL NECK DISSECTION FOR CARCINOMA OF THE EPIGLOTTIS

JOSEPH H OGURA, M D ,*†

St Louis, Mo

The presently accepted method for the surgical treatment of cancer of the epiglottis is total laryngectomy and radical neck dissection,[1-8] yet, in certain instances of carcinoma of the epiglottis, the surgeon must wonder whether sacrifice of the entire larynx and the commission of the patient to permanent tracheostomy is entirely necessary

The objective of the surgeon should be not only adequate removal of the lesion but also preservation of laryngeal physiology Peroral amputation of the epiglottis in the absence of nodal metastases has never received popular acceptance, since obviously a wide margin of safety could not be accomplished Although partial laryngectomy with preservation of cordal function is possible, it requires the creation of a large pharyngostoma The attendant dysphagia, drooling of saliva and multiple subsequent operations to effect closure have influenced surgeons into taking the easier course of total laryngectomy

Supraglottic subtotal laryngectomy and radical neck dissection as a one-stage operation for carcinoma of the epiglottis was developed in an attempt to conserve the function of the larynx. In South America the procedure is known as the partial horizontal laryngectomy[9,10] The procedure described here differs from the South American method in that primary closure is performed, rather than to create a pharyngostoma which necessitates a second operation at a later date

The rationale of the proposed surgical procedure is based

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To be published (When I presented this material at the Academy I learned that Ruedi was conducting a parallel study and that many of his ideas are similar I have been unable to obtain a copy of his paper and this reference is included here for completeness )

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## MICHIGAN MAN WINS HEARING SOCIETY AWARD

Stuart L Edmonds, Midland, Mich, was recently named winner of the American Hearing Society's Kenfield Memorial Scholarship, an award made annually to a prospective teacher of lipreading Mr Edmonds is the first man to receive the honor since establishment of the scholarship fund in 1937

Mr Edmonds has a bachelor's degree in speech correction, University of Michigan, and a master's degree in education, Eastern Michigan College of Education, Ypsilanti He has taught speech correction in his home State for five years

He is currently employed as field service consultant for the Michigan Association for Better Hearing, a job which has acquainted him with the urgent need for teachers of lipreading Through funds from the scholarship, he plans to take a course at Northwestern University in Methodologies for Teaching Speech Reading branes and ligaments The apex of this cone-shaped structure ends just superior to the anterior commissure of the true vocal cord, and is less than one-half the distance between the superior notch and the inferior border of the thyroid cartilage (see Fig 1)

Studies of larynges removed for primary malignant tumors of the epiglottis may show an invasion of the tumor into the

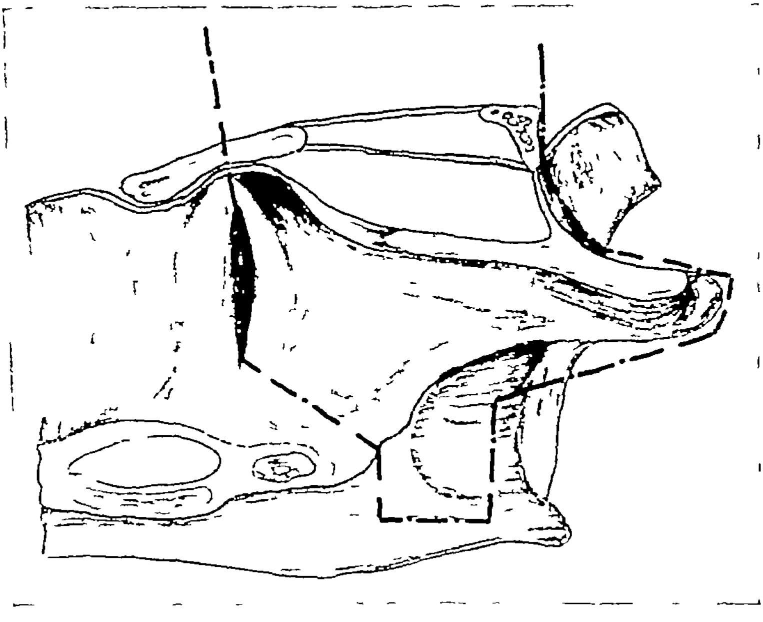

Fig 2 Surgical Criteria Lateral view of epiglottis and pre-epiglottic space vertical section The dotted line includes the area removed with a radical neck dissection

preepiglottic space, and anatomically this space is quite separate from the true vocal cords[13] In less advanced epiglottic carcinoma, when the lower edge of the tumor is at the region of the petiole, there may be microscopic evidence of further extension of tumor to the false cords Extension to the anterior commissure of the true cords, ventricle, aryepiglottic fold or arytenoids is a late manifestation In the latter instance, a bilateral neck dissection with total laryngectomy, on embryological, anatomical, clinical and pathological principles The embryological studies of Most[11] and the work of Rouviere[12] show that the lymphatic pathways from the supraglottic area are independent of those from the true cords and the subglottic areas The supraglottic portion of the larynx develops from the primitive pharynx while the glottis and subglottic area are derived from the superior extremity of the tracheal tube The ventricular bands, epiglottis and the anterior part of the aryepiglottic fold arise from the fourth branchial arch The separate lymphatic collecting pathways from the supraglottic and the cordal with subglottic area would suggest that the two sites could be divided from one another without violating sound principles of cancer surgery

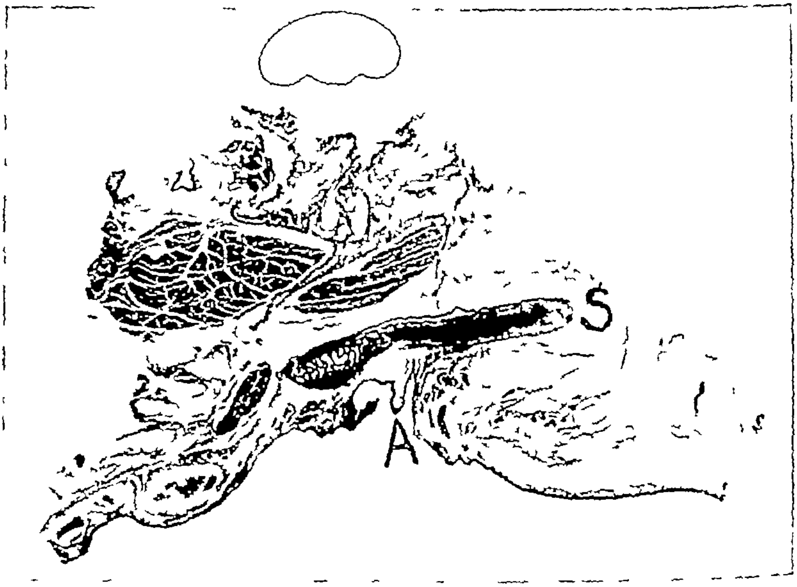

Fig 1 The relation of the anterior commissure to the thyroid cartilage Note the inferior position of the anterior commissure—A From the superior border of the thyroid cartilage S Low power vertical section

The preepiglottic space anatomically is confined between the hyoid and anterior commissure of the true vocal cords, shaped like a pyramid with the base up, and bounded laterally by the hyoepiglottic and hyothyroid and thyroepiglottic mem-

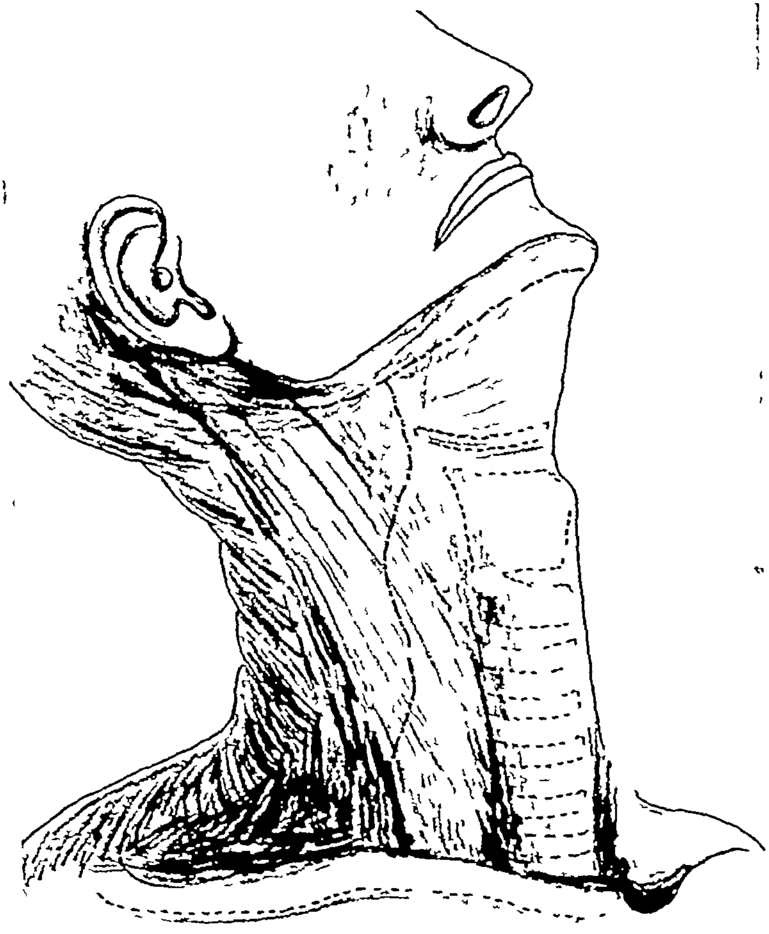

Fig 4 The Incision Note curved incision to minimize secondary contraction

from epiglottic carcinoma, continuity *en bloc* removal of the primary lesion and the cervical nodes must be done as a one-stage procedure if one is to maintain good oncologic principles Such an operation would create a large pharyngeal opening and would necessitate some method for closure In South America a secondary operation has been found necessary[8 9] It is my purpose to demonstrate that primary closure in my experience, has often been necessary LeRoux-Robert[11] has demonstrated that carcinoma of the epiglottis seldom extends below the cords into the subglottic area, hence, on an embryological, anatomical and pathological basis it should be possible, in selected instances, to remove the entire lesion and preserve the function of the true vocal cords if the resulting pharyngostoma could be closed

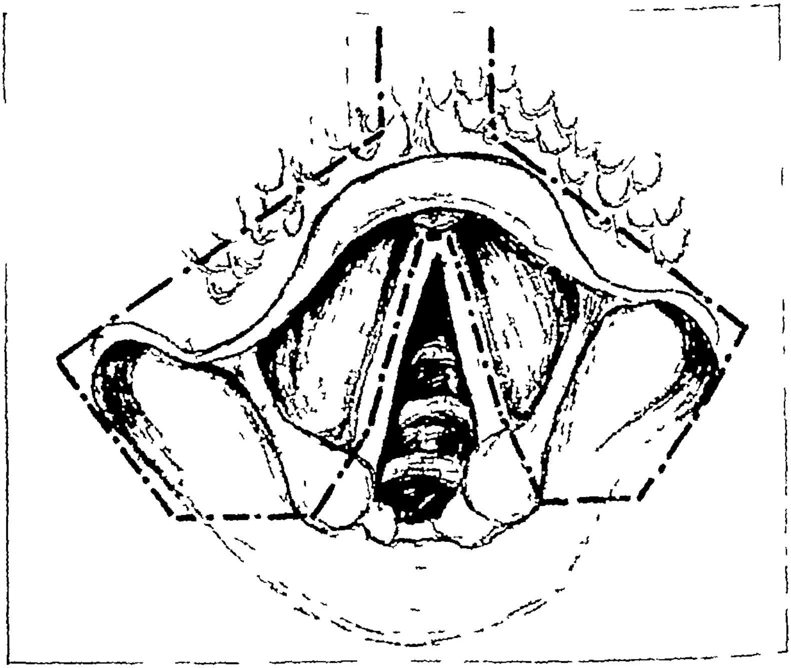

Fig 3 Surgical Criteria Mirror view of larynx dotted line indicates area of excision

Some surgeons have tried to solve the problem of surgical excision by a transhyoid pharyngotomy approach and amputating the epiglottis without horizontal transection of the thyroid cartilage Obviously, the entire preepiglottic space cannot be removed by this method The laryngofissure approach has the disadvantage in that the upper end of the incision will open the preepiglottic space and divide the cords at the anterior commissure

Since metastases to the lateral cervical nodes are frequent

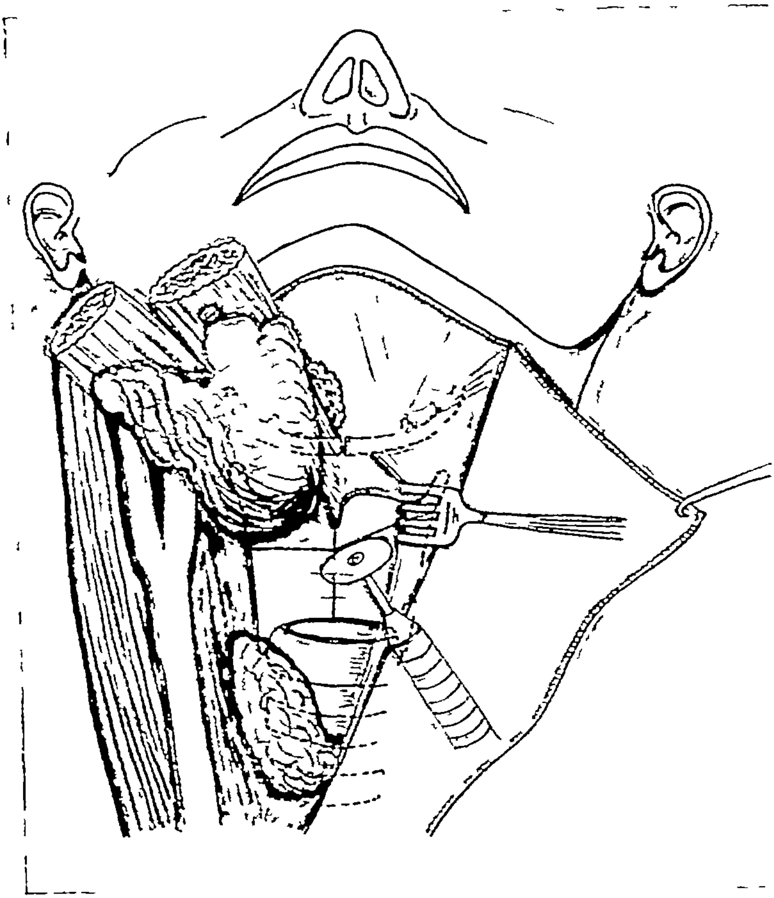

Fig 6 Thyroid cartilage is divided transversely one-third the distance from thyroid notch to the inferior border

*2* The lower border of the tumor should not extend below the petiole It is better if there is a greater margin of safety between the lower border of the tumor and the anterior commissure of the true vocal cords

*3* Lateral infiltration of the arytenoepiglottic folds and arytenoid edema must be absent

*4* The base of the tongue should be clear of tumor—(when

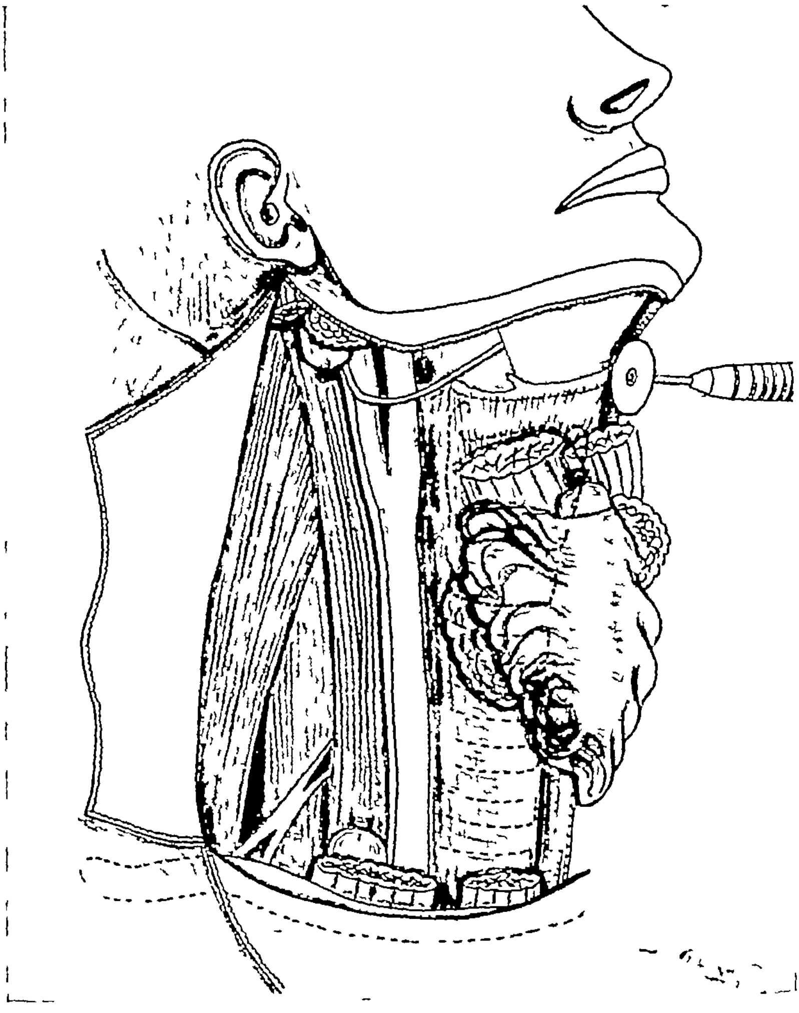

Fig 5 Radical neck dissection completed Note attachment to hyothyroid area sternohyoid and hyothyroid muscles are severed and hyoid bone is divided in midline

of this defect can be accomplished in one operation with restoration of the deglutition and cordal function

## SURGICAL CRITERIA

*1* The tumor involving the epiglottis should be limited entirely to the cartilaginous laryngeal surface, preferably more towards the free surface (see Figs 2, 3)

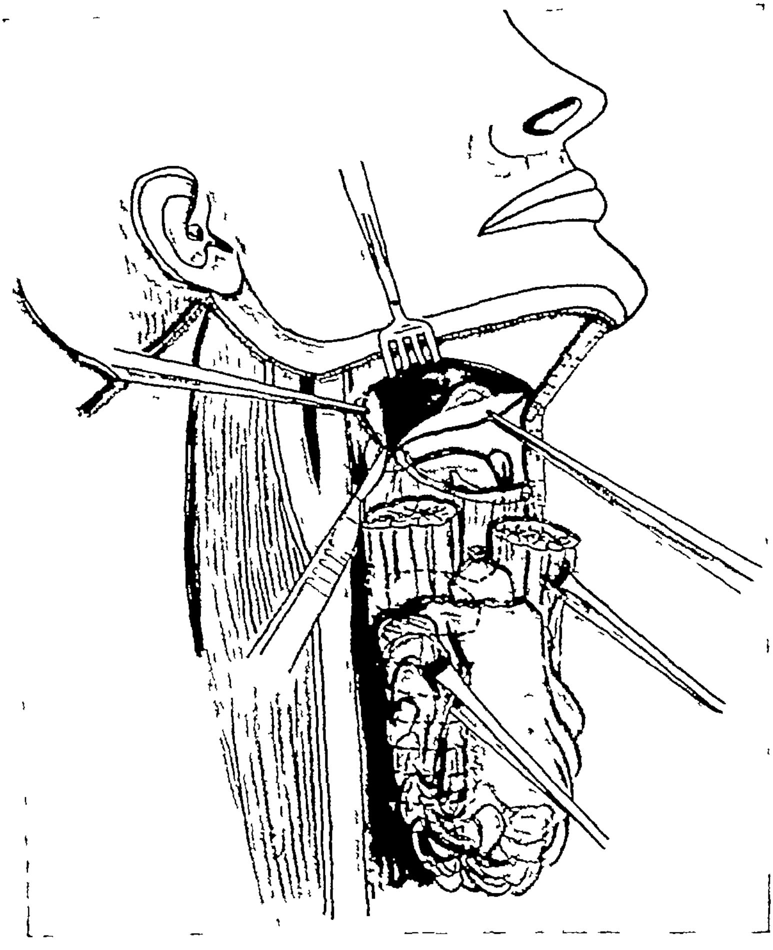

Fig 8 The lateral laryngo-pharyngeal wall is opened inferiorly along the posterior laryngopharynx.

frequently with exophytic lesions, they are more favorable clinically than those that are infiltrative and ulcerative

*8* Clinical invasion of the hyothyroid membrane should be absent

*9* If nodes are not palpable, a neck dissection is done on the side on which the tumor seems to show the greatest extent

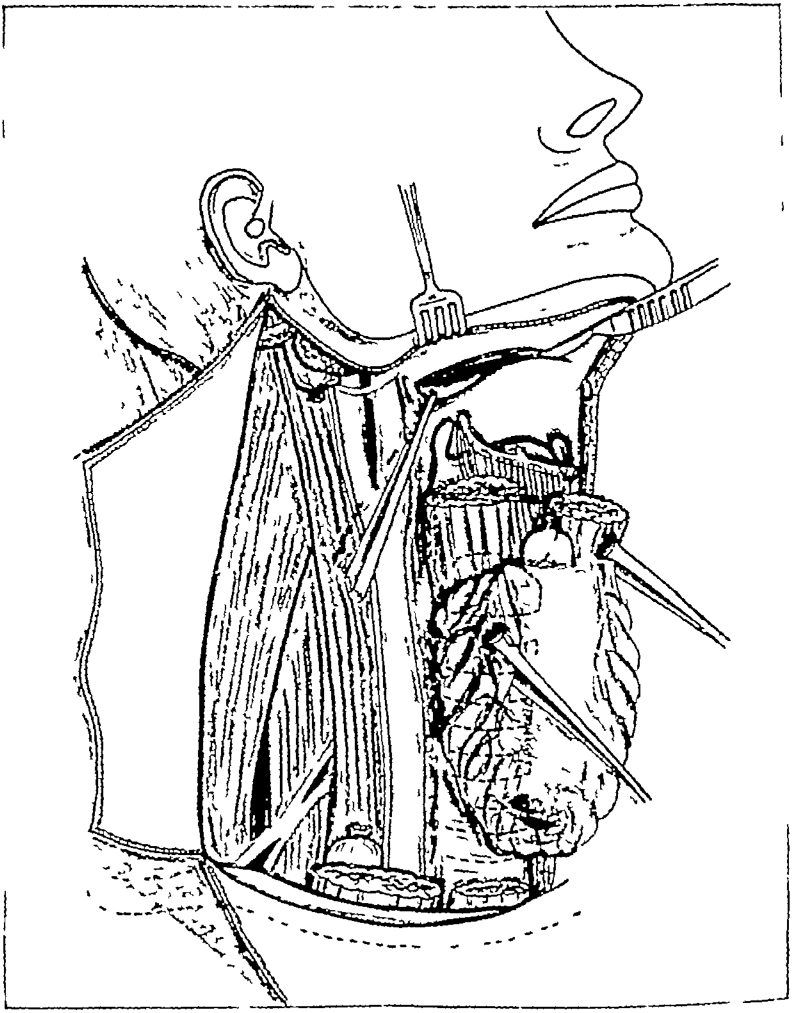

Fig 7 The pharynx is entered in the region of the vallecula and lateral glosso-epiglottic fold

the tip of the epiglottis on the glossal surface shows some tumor, a section of the base of the tongue is removed)

*5* The true vocal cords should be free of tumor and show no impairment of motion

*6* There should be no gross evidence of false cord invasion

*7* Because extension into the preepiglottic space occurs less

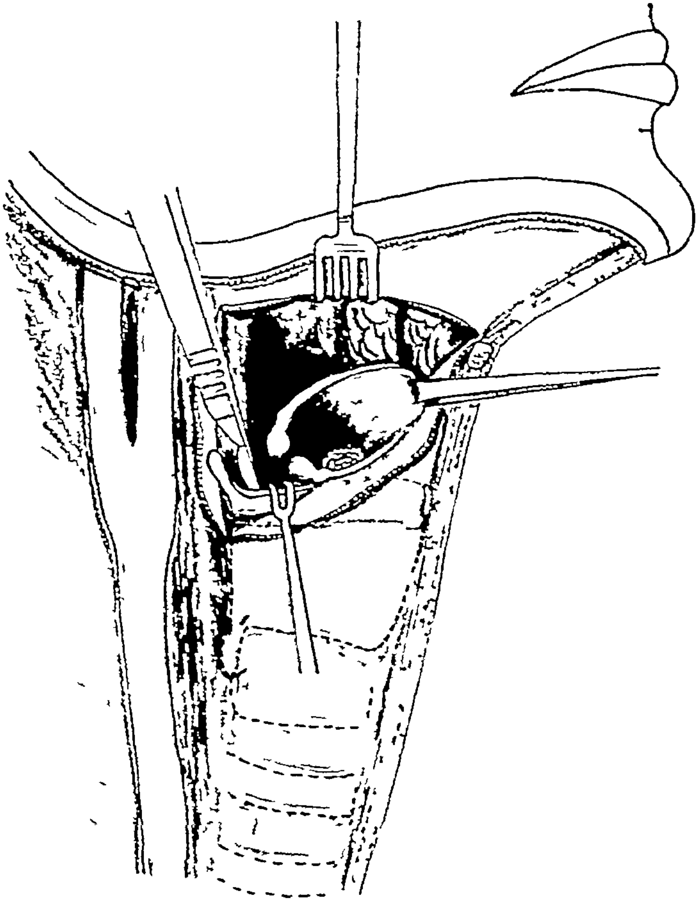

Fig 10 Dissection inferiorly and posterior to the superior cornu of the thyroid cartilage towards the horizontally transected thyroid cartilage

and endotracheal anesthesia is started A neck dissection is carried out in the classical fashion described by many authors over the past five decades[5, 16-20] The classical incision that has been modified and described by Huffman and Lierle has been used in this operation (see Fig 4) The neck dissection in this instance differs from the usual procedure in the following aspects No attempt is made to preserve the spinal accessory nerve whether or not nodes are palpable The

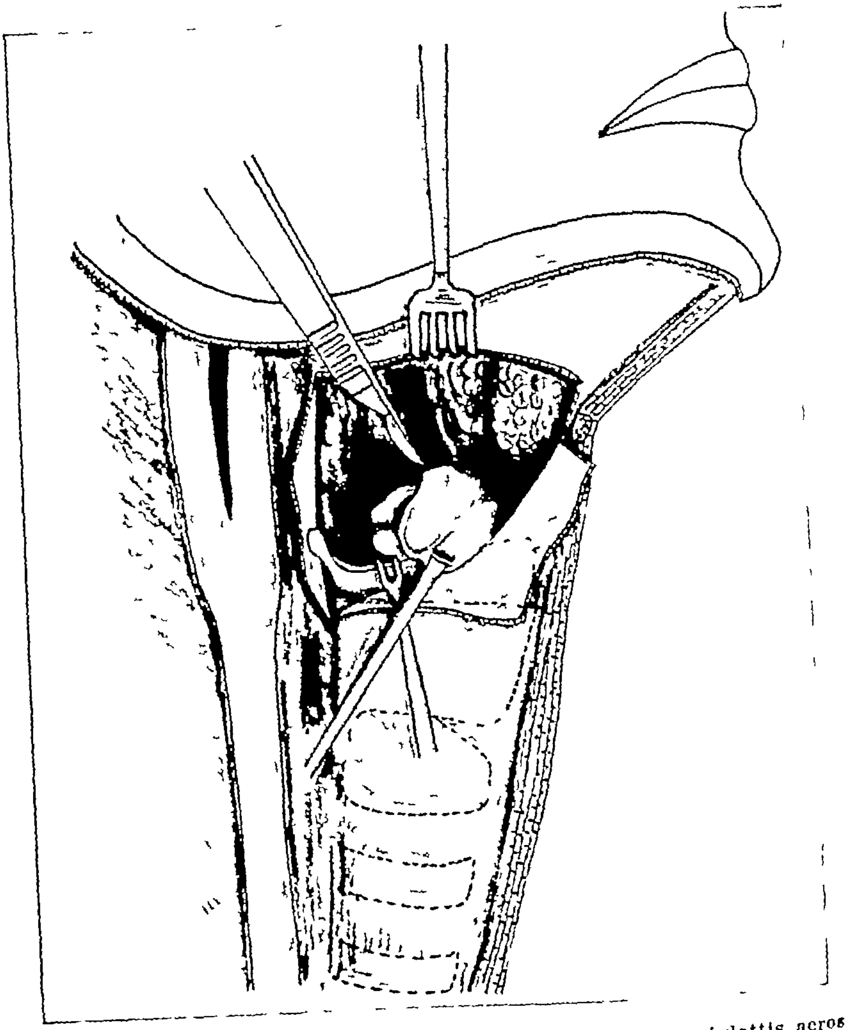

Fig 9 The base of the tongue is separated from the epiglottis across the midline

*10* Bilateral palpable nodes warrant a bilateral neck dissection

*11* Laryngograms using Dionisil as a contrast media are of great value[15]

TECHNIQUE

A preliminary tracheotomy is done under local anesthesia

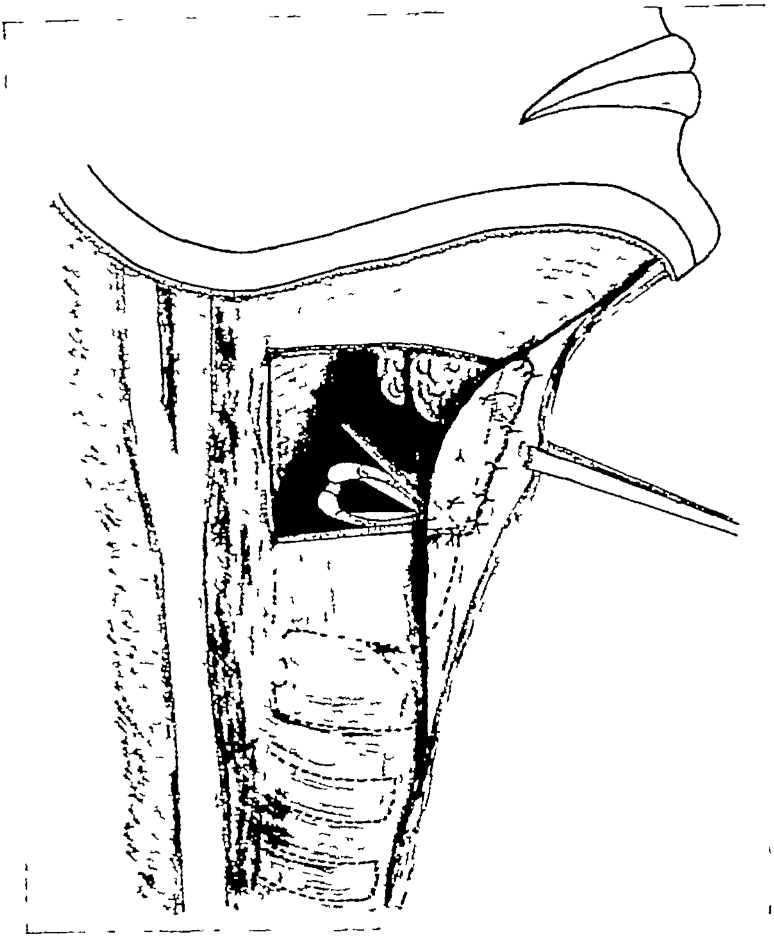

Fig 12 A thick split thickness skin graft is sutured on a muscle rotation flap

The suprahyoid muscles are separated from the hyoid bone on the side of the neck dissection to the midline, and the hyoid bone is divided in the midline and grasped with a tenaculum to be held inferiorly for a landmark (see Fig 5) It is not separated from the specimen

The thyroid cartilage is transectioned with a Stryker saw at a level one-third of the distance between the thyroid notch and the inferior border (see Fig 6)

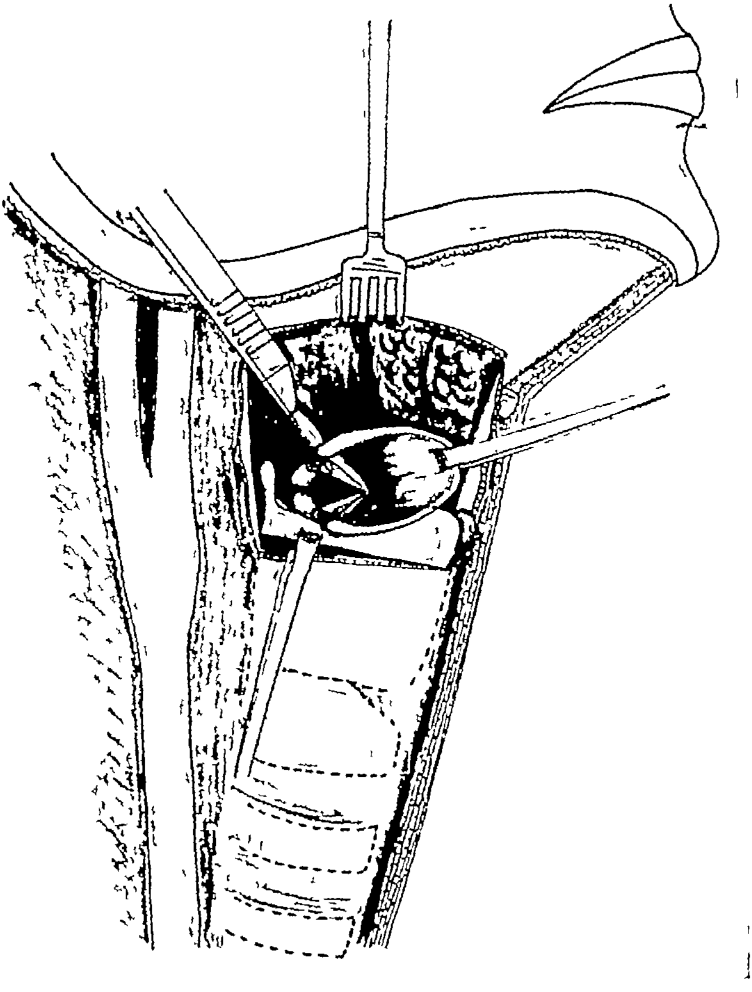

Fig 11 The aryepiglottic folds are sectioned close to the arytenoid and carried anteriorly into the horizontally transected thyroid cartilage, this separates the false cord-ventricle from the true vocal cords

sternothyroid and sternohyoid muscles are transected at the lower level of the thyroid cartilage on the side of the tumor to the midline A complete block neck dissection is performed, but the specimen is left attached to the lateral thyrohyoid area The thyroid lobe on the side of the neck dissection is removed, and great care is given to preserve the recurrent laryngeal nerve cision is carried posteriorly to the superior segment of the horizontally transected thyroid cartilage For further mobilization, the base of the tongue is separated from the epiglottis across the midline (see Figs 8, 9, 10)

The ipsilateral aryepiglottic fold is now sectioned close to the arytenoid cartilage Care should be taken not to expose the arytenoid cartilage The ipsilateral false cord is separated from the true cord, and at the same time further separation is carried anteriorly and laterally into the previously transected portion of the thyroid cartilage Dissection is then carried towards the anterior commissure of the true vocal cords separating it from the ventricle, false cord and epiglottis As dissection is carried across to the opposite side it will include a segment of the opposite transected thyroid cartilage, but less lateral laryngopharyngeal wall is sacrificed The contralateral false cord is divided from the true cord and final separation of the contralateral aryepiglottic fold close to the arytenoid is the last step (see Fig 11) In this manner the entire preepiglottic space together with the epiglottis, false cords, aryepiglottic folds and most of the ventricle (except its inferior surface represented by the superior surface of the true cord) is removed

Fig 14-A. Specimen removed

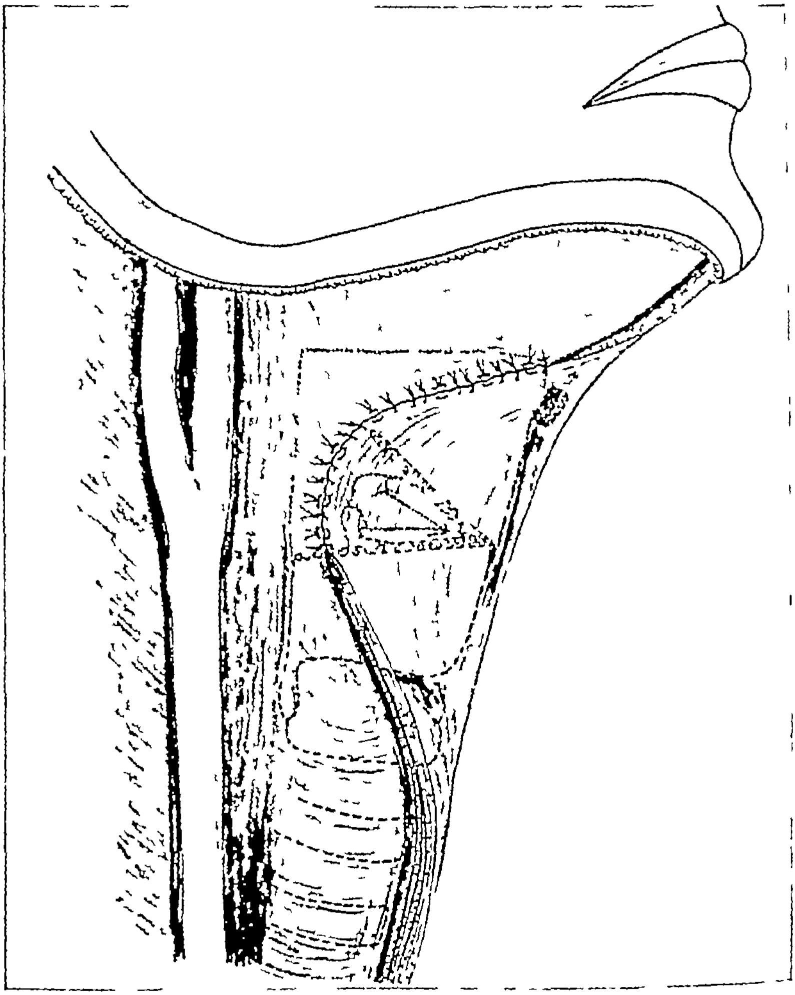

Fig 13 Laryngopharynx approximated with two layers of interrupted silk

On the side of the neck dissection, the sternothyroid and sternohyoid muscles are divided transversely from the midline toward the side of the neck dissection

A pharyngostoma is created by entering the pharynx superior and lateral to the vallecula (in the region where the suprahyoid muscles were separated from the hyoid (see Fig 7) With sharp dissection the entire lateral laryngopharyngeal wall is separated from the posterior wall, and the in-

A Penrose drain is placed into the lateral neck area, and the skin is closed by approximation of the subcutaneous tissues with silk and interrupted silk for the skin A tracheotomy tube is inserted following removal of the endotracheal tube

In the event that a bilateral neck dissection is necessary, then there are no strap muscles to rotate since they are removed with the transected thyroid cartilage In this case the entire tongue is mobilized and the laryngopharynx is obliterated by suturing the base of the tongue to the remaining larynx In the postoperative period, antibiotics and feeding by nasal tube is started

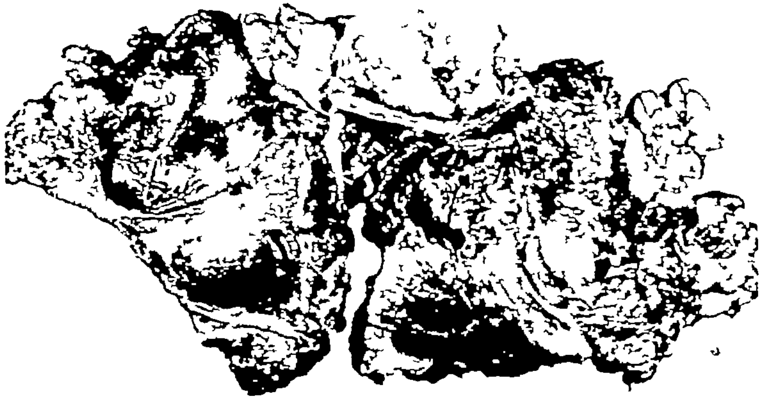

Fig 15-A. Specimen removed bilateral neck dissection

## RESTITUTION OF DEGLUTITION

It is obvious that since both superior laryngeal nerves are sectioned by this supraglottic approach, feeding difficulties will develop

After a period of ten days to two weeks, the patient is allowed to take food by mouth The patient must relearn

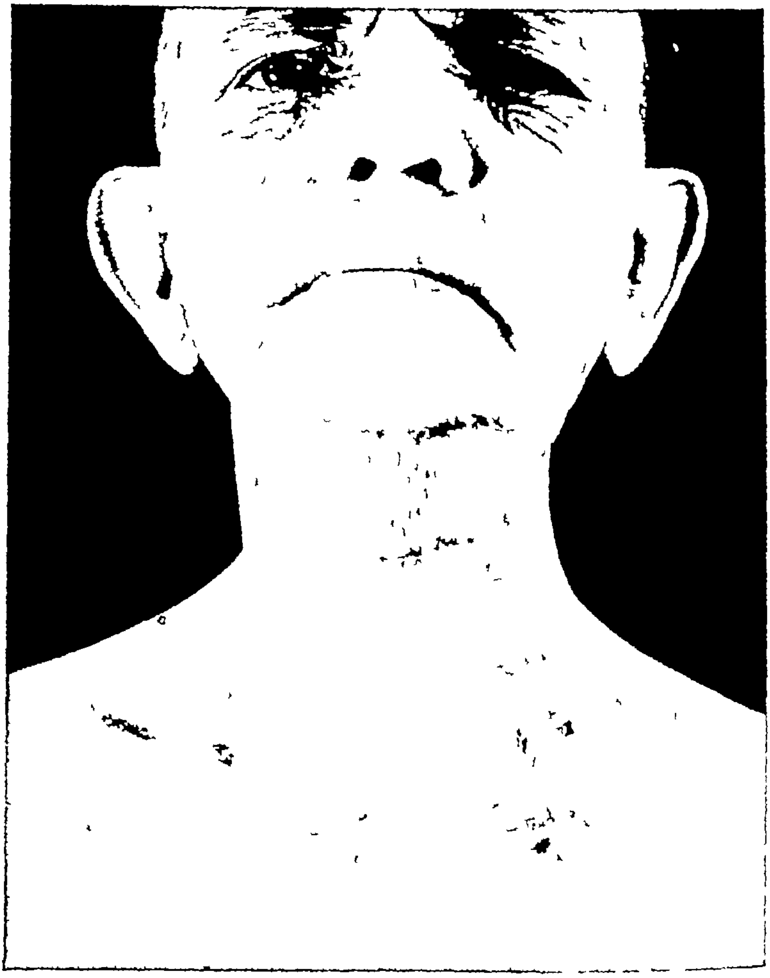

Fig 14-B Post-operative result

A nasal feeding tube is passed into the stomach A large muscle rotation flap is now created (see Fig 12) The opposite sternothyroid, thyrohyoid muscle is dissected free from the larynx and trachea and from the hyoid bone The flap can now be rotated, and a thick split thickness skin graft is sutured to the under surface of the muscle The muscle flap and skin graft close off the pharyngeal defect by approximating it with the constrictor muscles Uusually two or three layers of reinforcing sutures will be necessary (see Fig 13) first some material may be aspirated into the trachea, but after several days of effort all of our patients were able to overcome this handicap Once effective deglutition is established, the tracheotomy opening may be closed All of our patients have a good voice immediately

## RESULTS

Fifteen patients with epiglottic carcinoma have been operated upon with unilateral neck dissection and one with a simultaneous bilateral neck dissection (see Figs 14, 15) In four other patients with lateral laryngopharyngeal wall cancer, the transhyoid approach without removal of any portion of the larynx entailed closure of the pharynx by the rotation of a muscle flap and skin graft Experiences in the entire group thus far extends to a three-and-one-half year followup period No local recurrences have resulted in the remaining larynx to date Fixation of vocal cord occurred in one instance where the arytenoid cartilage was exposed One patient died of a coronary occlusion one year after surgery, and autopsy showed no evidence of carcinoma Seven of fifteen patients had positive nodes confirmed pathologically The high frequency of metastatic nodes from epiglottic carcinoma is suggested in this small series

Secondary neck dissection has been necessary in one instance In this patient a node became palpable six months after the first operation

## SUMMARY AND CONCLUSION

Fifteen patients with carcinoma of the epiglottis have been operated upon, using a technique for *en bloc* removal of the primary lesion, together with a radical neck dissection

Reconstruction of the laryngopharynx by a muscle flap and skin graft has been effective in the early rehabilitation of the patient

Preservation of the function of the true vocal cord is possible The patients can have not only a good voice and a normal airway, but also are able to swallow normally without

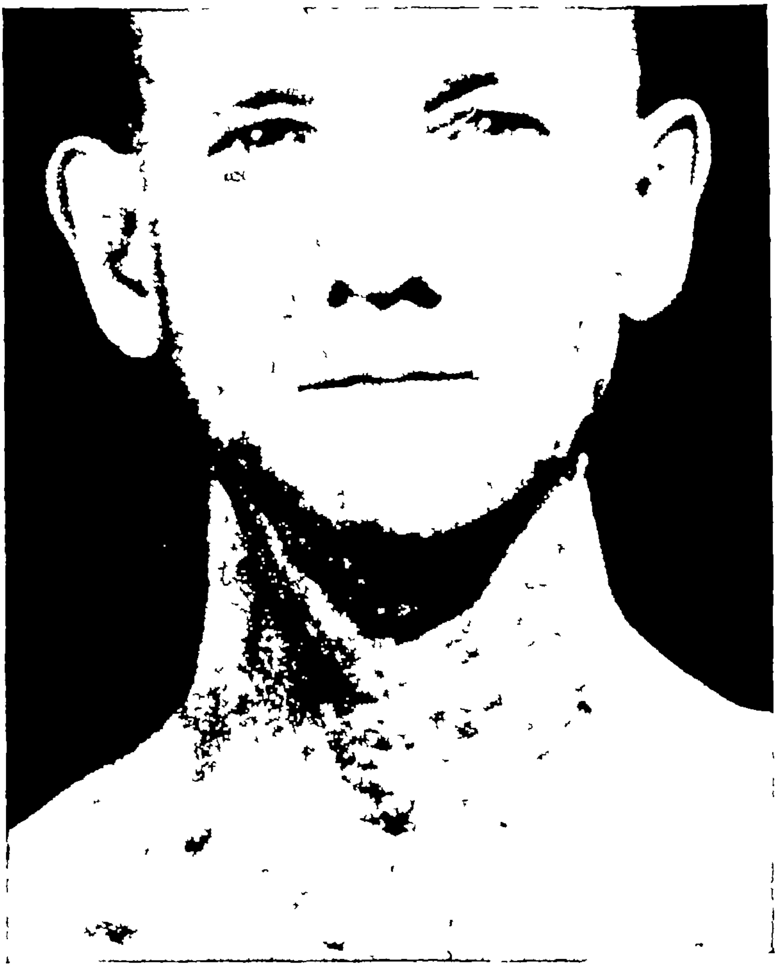

Fig 15-B Postoperative result

deglutition At first it is a conscious effort on the part of the patient, but later swallowing becomes a reflex act Thin cereal is tolerated more easily than water until the patient becomes accustomed to the sensation of the passage of food In the initial attempts at swallowing, the tracheotomy tube is closed with a cork, and the patient is told to swallow and breathe out utilizing the larynx to clear the mucous and food from the true vocal cords Usually for one small amount of food this process of clearing the throat with swallowing must be repeated several times to swallow a bolus effectively At

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## POST GRADUATE COURSE IN RHINOPLASTY, RECONSTRUCTIVE SURGERY OF NASAL SEPTUM AND OTOPLASTY

An intensive post graduate course in Rhinoplasty, Reconstructive Surgery of the Nasal Septum and Otoplasty will be given July 12, 1958, to July 26, 1958, by Dr Irving B Goldman and staff at the Mount Sinai Hospital, New York, in affiliation with Columbia University

Candidates for the course should apply to Registrar for Postgraduate Medical Instruction, the Mount Sinai Hospital, Fifth Avenue and One-Hundredth Street, New York 29, New York the protective function of the epiglottis, aryepiglottic folds or false cords *

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*The author is deeply indebted to Dr Donald Chen Resident in Otolaryngology for the illustrations on the technique

1955, (each nasopharyngeal area was treated through a lateral portal 6x7 cms each portal received a total of 600 $r$ in air) There was temporary relief of symptoms following the X ray therapy until December 14, 1955 when she again complained of the 'popping and fullness in the right ear which she felt was worse than ever Examination with a nasopharyngoscope showed the central adenoid mass to be about the same

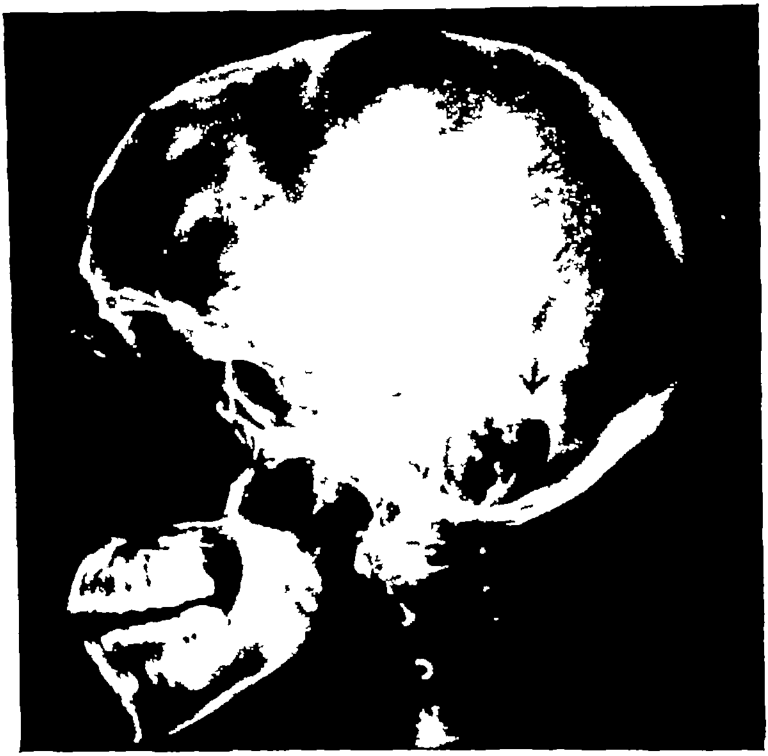

Fig 1 True cholesteatoma (epidermoid) of the left occipital and temporal bones with invasion of some of the mastoid cells but without involvement of the middle or inner ear Approximate measurement 3 5x4 5 cms Lateral view

Various medications including antihistamine and vasoconstrictor drugs were helpful only at times

On March 5 1956 the patient complained of dizziness which had been present for two or three weeks She found it difficult to describe this dizziness It was not a whirling sensation but an unsureness or a light headedness akin to giddiness It had come on without warning and did not seem to be related to her ear symptoms of 'popping" or fullness It was worse when she looked up but could be relieved by bending her head down or by chewing gum.

# PSEUDO-VERTIGO FROM TRUE CHOLESTEATOMA OF THE SKULL *†

SHIRLEY HAROLD BARON, M D ,

San Francisco, Calif

True epithelial cholesteatomata originating in the cranial chamber elsewhere than in the middle ear are uncommon They represent only a fraction of one per cent of intracranial neoplasms as a whole,[1] and are seldom, if ever, thought of as a cause of dizziness An exception to the rule is the case to be reported in which skull X-rays revealed a large cholesteatoma of the left occipital and temporal bones This tumor, though *not* involving the middle or inner ear, proved to be the cause of the patient's dizziness

## CASE REPORT

Mrs J , age 43, the wife of a physician, was seen first in June 1953, for an acute bilateral, suppurative, maxillary sinusitis It was not until three years later that she complained of dizziness In the interim she was seen many times

In February, 1954, she complained of a dullness and 'popping" in her right ear following an airplane trip In March, 1954, she complained of a peculiar sensation, a dullness in both ears An audiogram done then showed normal hearing There was no disease noted excepting boggy nasal turbinates suggesting a *vasomotor rhinitis* In November, 1954, the patient complained of discomfort in the left side of her face with some pain referred to the front of her left ear and a 'filling up" in both ears A week later the ear sensation had disappeared, but there was still a feeling of "something being in the left side of the nose and face This eventually disappeared

In June, 1955, the patient complained again of a feeling of fullness in both ears with intermittent "popping' and a small tender area back of her left mastoid This tenderness was thought to be due to an inflamed lymph node (The patient had some scaling of her scalp in this region)

On August 2, 1955, she still complained of intermittent 'popping' and fullness in her ears Examination with a nasopharyngoscope showed a small amount of lymphoid tissue above each torus and in the vault of the nasopharynx X ray therapy to the nasopharynx was suggested and then administered by a roentgenologist between August 5 and August 22

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*Read at the meeting of the Western Section American Laryngological Rhinological and Otological Society Inc Beverly Hills Calif Jan 18 1958

†From the Department of Surgery Division of Otolaryngology Stanford University Medical School and the Department of Otolaryngology Mount Zion Hospital

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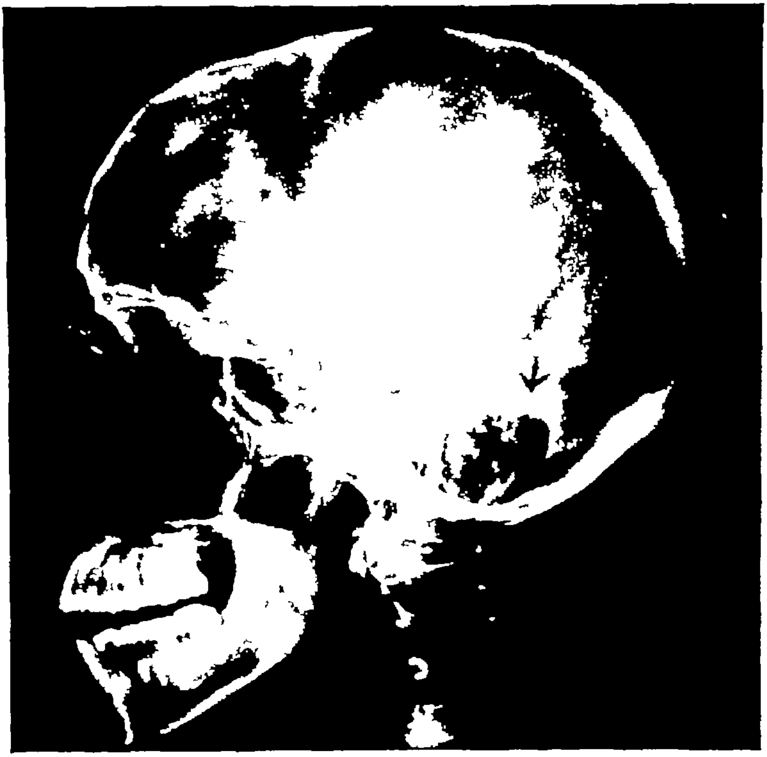

Fig 1 True cholesteatoma (epidermoid) of the left occipital and temporal bones with invasion of some of the mastoid cells but without involvement of the middle or inner ear Approximate measurement 3 5x4 5 cms Lateral view

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# PSEUDO-VERTIGO FROM TRUE CHOLESTEATOMA OF THE SKULL *†

SHIRLEY HAROLD BARON, M D ,

San Francisco, Calif

True epithelial cholesteatomata originating in the cranial chamber elsewhere than in the middle ear are uncommon They represent only a fraction of one per cent of intracranial neoplasms as a whole,[1] and are seldom, if ever, thought of as a cause of dizziness An exception to the rule is the case to be reported in which skull X-rays revealed a large cholesteatoma of the left occipital and temporal bones This tumor, though *not* involving the middle or inner ear, proved to be the cause of the patient's dizziness

## CASE REPORT

Mrs J , age 43, the wife of a physician was seen first in June, 1953, for an acute bilateral, suppurative, maxillary sinusitis It was not until three years later that she complained of dizziness In the interim she was seen many times

In February, 1954, she complained of a dullness and 'popping" in her right ear following an airplane trip In March 1954, she complained of a peculiar sensation, a dullness in both ears An audiogram done then showed normal hearing There was no disease noted excepting boggy nasal turbinates suggesting a vasomotor rhinitis In November 1954, the patient complained of discomfort in the left side of her face with some pain referred to the front of her left ear and a 'filling up' in both ears A week later the ear sensation had disappeared, but there was still a feeling of "something being in the left side of the nose and face This eventually disappeared

In June, 1955, the patient complained again of a feeling of fullness in both ears with intermittent "popping" and a small tender area back of her left mastoid This tenderness was thought to be due to an inflamed lymph node (The patient had some scaling of her scalp in this region)

On August 2, 1955, she still complained of intermittent popping' and fullness in her ears Examination with a nasopharyngoscope showed a small amount of lymphoid tissue above each torus and in the vault of the nasopharynx X ray therapy to the nasopharynx was suggested and then administered by a roentgenologist between August 5 and August 22,

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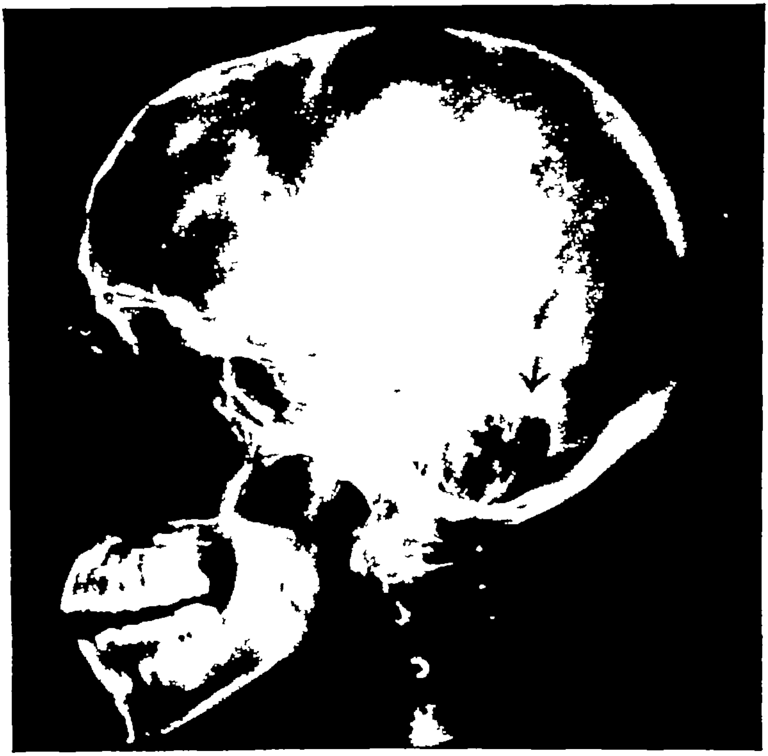

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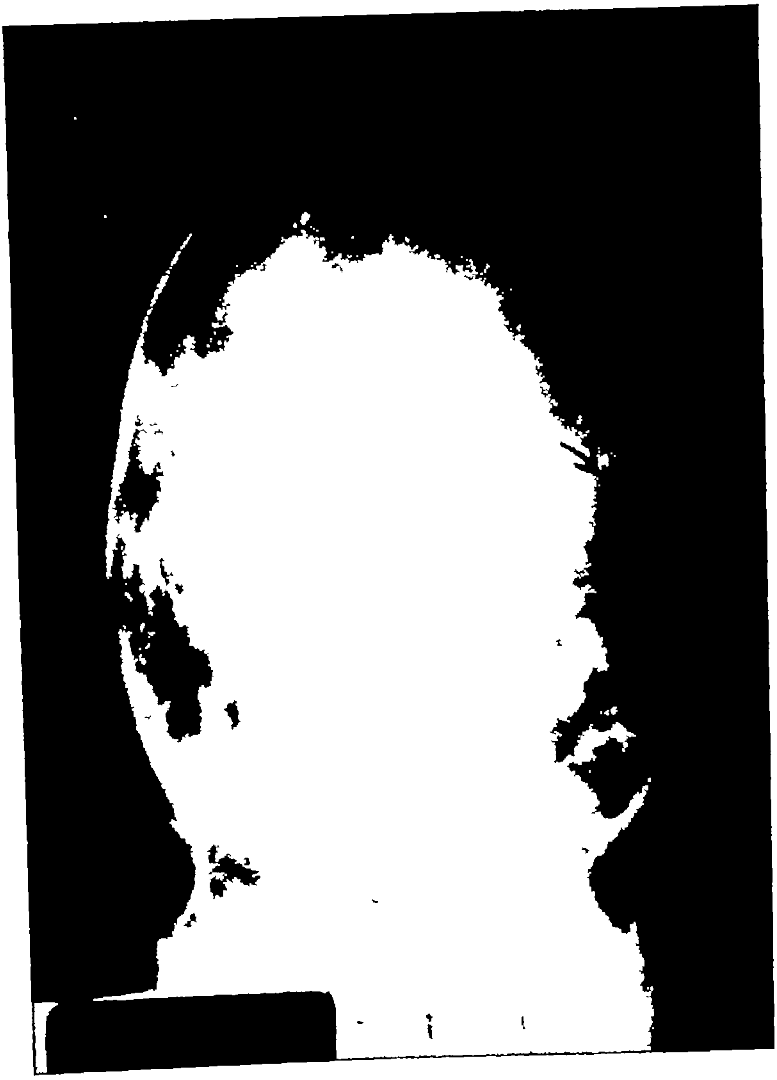


Fig 2 Same as Fig 1 sub-mento-vertical view

Examination showed no change in the appearance of the nasopharynx The eardrum membranes were normal The audiogram showed a slight loss in hearing for low tones in both ears (15 db at 250 and 10 db at 500 cycles per second) A cold caloric (5 cc ice water) test for vestibular function showed normal responses for both ears A neurological examination revealed no abnormality

The skull was X rayed The films revealed an oval zone of diminished density involving the left occipital and temporal bones encroaching upon some of the pneumatized portion of the mastoid process but not involving the middle or inner ear This defect measured about 3 5x4 5 cms (see Figs 1, 2) The lesion was considered to be a true cholesteatoma or epidermoid It was felt that it should be removed surgically

Surgery was done on April 2 1956 with Dr O W Jones a neurosurgeon who used a craniotomy approach over the site of the cholesteatoma A small horseshoe-shaped incision was employed the anterior limb starting at the tip of the mastoid process curving upward, then backward and down When the pericranium was reflected caudally, grumous pearly gray material characteristic of a cholesteatoma was found posterior to the tip of the mastoid process Further exposure was obtained by removing some of the outer table of the skull toward and including the occipital bone It was then possible to remove the sac of the cholesteatoma from the dura which covered the left cerebellar hemisphere and the lateral sinus The dura was compressible and trans parent and about one-half inch below its surface the partially atrophic cerebellum could be seen There was fluid between the dura and the cerebellum The attachment of the tentorium had been displaced mesially

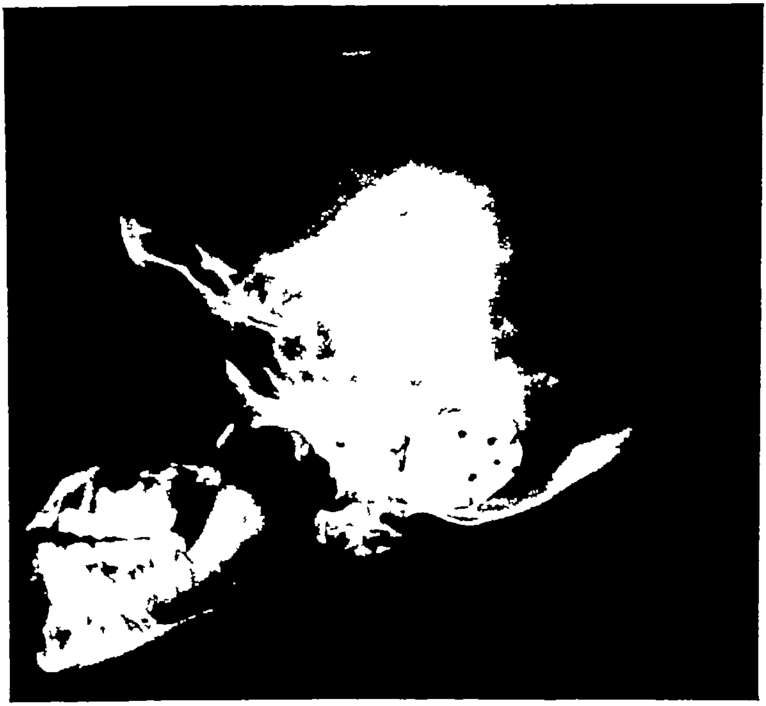


Fig 3 Tantalum plate covering the defect in the skull resulting from surgical removal of the cholesteatoma Lateral view

After Dr Jones removed the sac from the dura I removed that portion of the sac wall which had eroded the mastoid cells This was done with magnified vision and required removal of some of the underlying mastoid

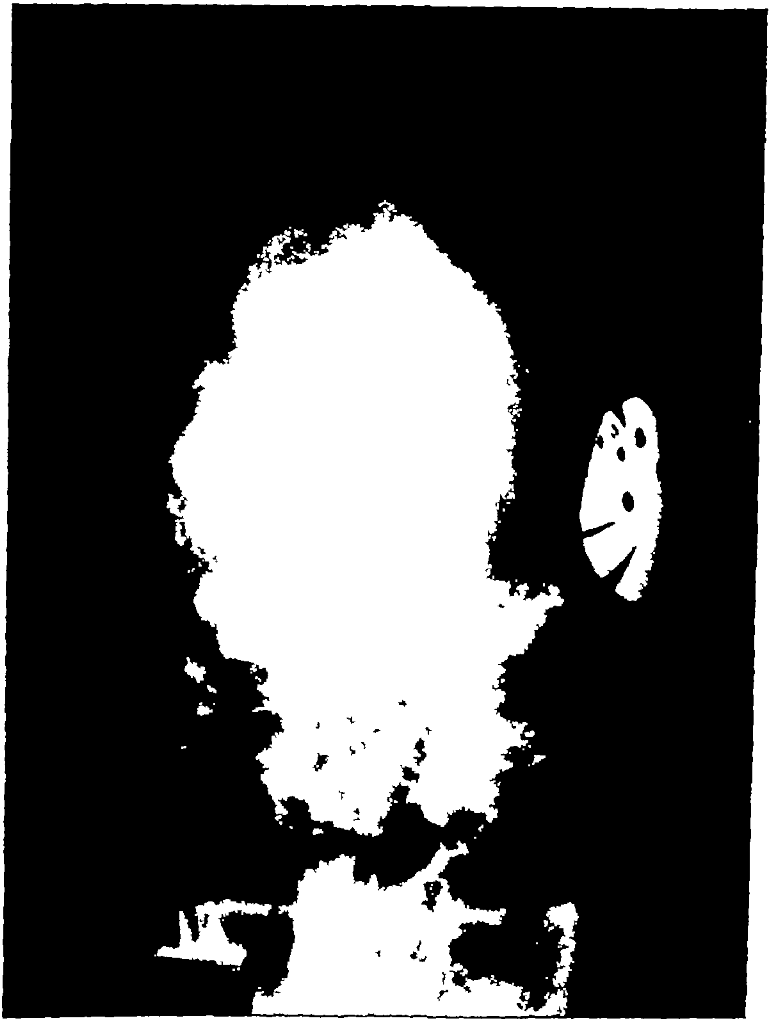


Fig 4 Same as Fig 3 sub-mento-vertical view

cells for complete elimination of the matrix When these cells were removed, the mastoid antrum came into view Its lining membrane appeared healthy and uninvolved

Gelfoam was placed into the mastoid antrum and into the defect in the mastoid cells made at surgery and by the lesion itself A tantalum plate was fashioned for the defect in the skull and held in place with two sutures of tanalum wire (see Figs 3 4) The scalp was closed, layer by layer, with sutures of nylon

The course was uneventful The left tympanic membrane examined the day after surgery, showed the bluish color of a moderate hemotympanum, which disappeared within four weeks There was a feeling of fullness, but not of deafness The sutures were removed on the fourth postoperative day The patient was dismissed on the next day

The dizziness disappeared following surgery and has not recurred to date The patient has complained of a sensation of an echo in her left ear but feels that her hearing is normal She still experiences 'popping" in both ears An audiogram done on June 14 1957, revealed a slight loss of hearing as compared with that of February, 1954, but the slight loss was about equal for both ears The readings were for the right ear 250 20, 500 10 1000-0, 2000 5 4000 10, 8000 15, for the left ear 250 25 500 10, 1000 minus 5 2000 10, 4000 10 8000 5

## COMMENT

The discovery of such a large lesion of the skull in this patient the wife of a physician after she had been under my care for three years was a bit embarrassing for, considering its size, the cholesteatoma must have been present all of those three years probably longer, yet in retrospect, there was nothing that suggested an indication for X rays of the skull until the symptom of dizziness appeared

The use of nasopharyngeal irradiation, worthless to this patient merits criticism This is self-criticism and criticism of others who have developed the habit of resorting to irradiation therapy as a crutch for the patient with tubal symptoms when no other treatment seems available Irradiation therapy in patients with more defined tubal symptoms has proven disappointing in my experience so certainly there was little excuse for my having suggested it here

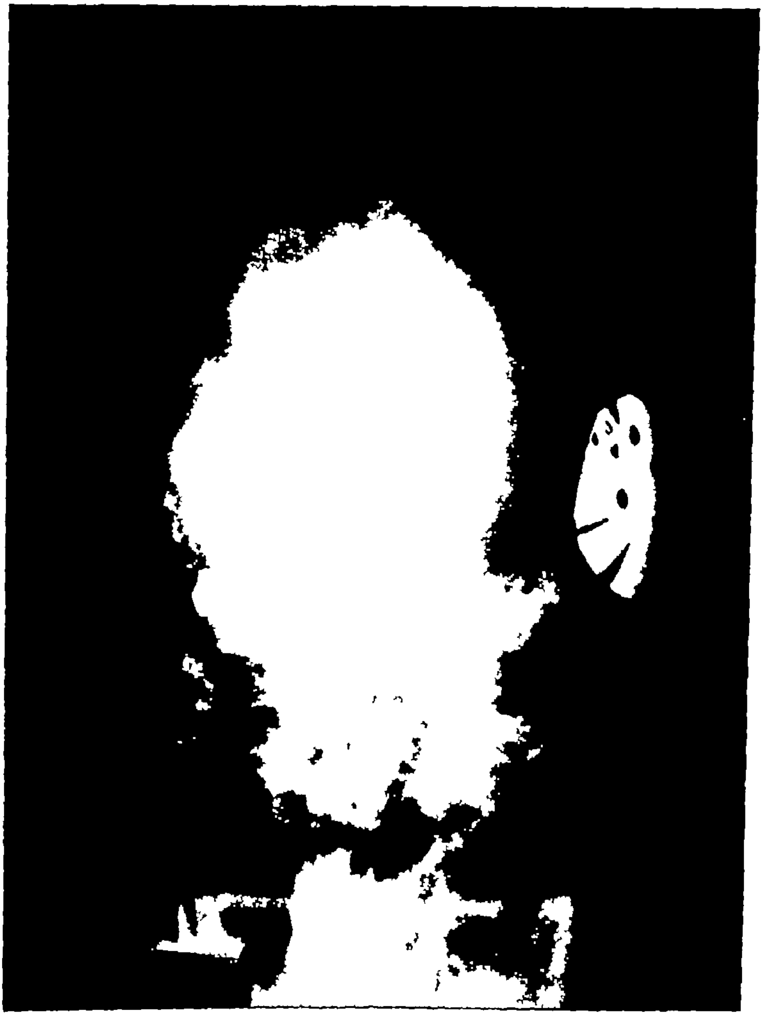
The sensation of an echo in the left ear is difficult to explain The alteration in the mastoid air cell system could hardly be considered a cause in view of the fact that an echo sensation does not exist in those patients who have had mastoidectomies which result in a much greater alteration in the mastoid anatomy

It is unlikely that the intermittent ear popping is related to the skull cholesteatoma It is probably the result of the vasomotor instability of this patient

## DISCUSSION

Since there occasionally exists some confusion in the terminology of the classification of cholesteatomata, it might be worth while to review Wittmaack's[3,4] classification, which is generally used Sometimes the terms "true cholesteatoma" and "primary cholesteatoma" are used interchangeably, but incorrectly so Recently Day[5] titled a paper, "A Primary Cholesteatoma of the Middle Ear," but in the text of his article he referred to the lesion as a "cholesteatoma verum" or a true congenital cholesteatoma The incorrect use of "primary" in this instance was probably an oversight

A cholesteatoma is a tumor which is surrounded by a thin shell of epidermis and connective tissue in which is accumulated desquamated horny epithelium Wittmaack classified



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The course was uneventful The left tympanic membrane examined the day after surgery, showed the bluish color of a moderate hemotympanum, which disappeared within four weeks There was a feeling of teatoma of the temporal bone which had not been recognized previously in spite of the fact that the X-ray showed a defect in the skull three years earlier

The more common situations of a true cholesteatoma are *1* in and about the temporal bone, *2* in the leptomeninges of the cerebral base, *3* in the cerebral ventricles, these last being endothelial tumors, and *4* in the bones of the skull at places remote from the middle ear, such as the occipital, parietal or frontal bone The latter are of the epidermoid variety alone and seem to originate between the two tables of the skull, the inner table being the first one to become ballooned out and absorbed as the growth enlarges Such a tumor is represented by the lesion found in the case reported

Cushing ventured the opinion that true cholesteatoma rather than pseudocholesteatoma may be the rule in the middle ear cholesteatomas, and that the cholesteatoma is responsible for the otitis media rather than the reverse Except for the primary type of pseudocholesteatoma, it is unlikely that any otologist would support Cushing's view

*Pseudocholesteatoma* The primary, or genuine type is thought to come from a spontaneous perforation of Shrapnell's membrane The perforation itself is the result of marked epitympanal absorption of air from a shutting of the tubotympanic space by adhesive bands that are thought to occur in the course of otitis neonatorum From the margins of the perforation epithelium invades the attic of the tympanum (epitympanum) and the antrum of the mastoid process and, with the accumulation of the trapped products of desquamation, the pseudocholesteatoma gradually enlarges, causing pressure rarefaction of the underlying bone This type usually is seen only when secondary suppuration occurs, or when complications arising from increased intracranial pressure cause death They have been discovered during life as the result of a search for the cause of progressive deafness in certain patients

The secondary type of pseudocholesteatoma is the sequel of a chronic otitis media in which the epithelium from the external auditory canal, or from the margin of the tympanic cholesteatomas into two main types *1* true cholesteatoma, and *2* pseudocholesteatoma The pseudocholesteatomas are divided into *a* the primary, or genuine, type, and *b* the secondary type

*True Cholesteatoma* This tumor is considered to be derived from an embryonic rest and consists of concentric polygonal lamella, composed of epidermoid cells which are devoid of nuclei Between these lamellas are found cholesterol crystals in greater or lesser quantity Surrounding the mass is a membrane, the cholesteatoma matrix, which has an outer layer of connective tissue attached to bone, and an inner epidermal layer These are referred to in Bancroft[6] as "epidermoids" He states, "Epidermoids, sometimes loosely called 'cholesteatomas,' occasionally arise in the diploe of the skull The lesions are congenital and are really cysts lined with squamous epithelium and entirely filled with flaky white epithelial debris"

There is no recognizable difference pathologically between the "true" and the "pseudo" cholesteatoma

The true cholesteatoma, also known as pearly tumor, is found in the skull, not usually associated with the ear

Cushing,[1] in 1922, in a very excellent article, associated the names of Cruveilhier, Johannes Mueller and Virchow with the true cranial or intracranial cholesteatoma, and credits Cruveilhier with coining the name "pearly tumor"

Cushing stated, "The cholesteatomata remote from the temporal bone are unusual tumors, and certain types of them excessively so They are so uncommon, indeed, and excite so much interest when disclosed unexpectedly postmortem, or more rarely in the course of an operation on the brain, that they are prone to find their way into medical literature So far as I am aware, the condition has never been diagnosed except at autopsy or operation Certain of these lesions, however, despite their obscurity, should be quite capable of recognition because of the characteristic changes in the bone which the X-ray may disclose"

Cushing reported an interesting case of a very large choles-

# REPORT OF A RECENT STUDY ON DIHYDROSTREPTOMYCIN OTOTOXICITY *†

ARAM GLORIG, M.D.,

Los Angeles, Calif.

## INTRODUCTION

The ototoxicity of streptomycin (SM) and dihydrostreptomycin (DHSM) has been recognized since 1946. Soon after streptomycin first became available for therapeutic purposes untoward effects centering mainly around the vestibular system were noticed. Attention was directed towards these effects by patients' subjective complaints of vertigo, loss of visual focus, imbalance, slight sensations of nausea and even spontaneous nystagmus. On the strength of these complaints and at the suggestion of Dr. Edmund P. Fowler, Jr., the author conducted a study designed to determine the extent and location of the lesion apparently produced by streptomycin. The results of the study were reported in 1947 in the *Annals of Otology, Rhinology and Laryngology*.

Shortly after the completion of this first study, about 1948 or 1949, there appeared on the market a modification of streptomycin called dihydrostreptomycin. When dihydrostreptomycin was used as a therapeutic agent, complaints related to vestibular pathology were less numerous. Dihydrostreptomycin seemed to be less toxic than streptomycin. We were soon to discover, however, that the one set of symptoms were replaced with another. Instead of showing vestibular symptoms, numerous patients began to show evidence of hearing loss. This was indeed a complete change. It was somewhat of a surprise and, at first, quite unbelievable. Some of the patients began to have difficulty communicating when spoken

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†Research Center, Subcommittee on Noise in Industry, Los Angeles, Calif.

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membrane, invades the middle ear or the epitympanum and the antrum of the mastoid process It progressively increases in size in the pattern described for the *primary type* of pseudocholesteatoma

## SUMMARY

A report of a patient having had a form of dizziness caused by a true cholesteatoma of the skull has been presented This tumor was situated in the left occipital and temporal bones with invasion of some of the mastoid cells but without involvement of the middle or internal ear The origin of this cholesteatoma was probably in the diploe of the occipital bone

This patient's dizziness, a pseudo-vertigo, was cured by the surgical removal of the cholesteatoma The surgical technique has been described with the aid of slides of photographs in color taken during the surgery

The dizziness undoubtedly was caused by pressure of the cholesteatoma upon the left hemisphere of the cerebellum, which evidenced some atrophy (as seen through the transparent dura) at the time of surgery Apparently the surgical relief of this pressure permitted the return of function

## CONCLUSION

True cholesteatoma of the skull without involvement of the middle or inner ear must be added to the list of possible causes of the varied forms of dizziness

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516 Sutter Street

widespread published support for the belief that streptomycin is much more toxic to the vestibular apparatus than is dihydrostreptomycin, and that dihydrostreptomycin is more toxic to the auditory system than is streptomycin. In general the recent articles also confirm earlier estimates of the amount of drug necessary to produce toxic effects. Specifically, in the case of streptomycin, if 1 to 2 gms. per day are used, vestibular symptoms will usually occur in three to four weeks. If the dosage is limited to 1 gm. twice a week the appearence of symptoms is delayed considerably. The time of appearance of symptoms seems to be directly related to the total amount of drug used, and it also appears to be dependent upon the amount of time between doses.

Similar statements can be made about dihydrostreptomycin and its effect on the cochlear division of the VIIIth nerve. The hearing losses produced by dihydrostreptomycin are usually bilateral. They are primarily in the upper frequencies unless severe losses occur, in which event the speech frequencies also are affected. Most of the studies indicate that 10 to 15 per cent of patients treated with dihydrostreptomycin sustain a hearing loss after the total dose reaches 50 to 60 gms.

One point is very clearly made in most of the reports: when renal insufficiency exists, the toxic effects of the drug are increased, and more severe hearing loss results. This is to be expected, as streptomycin and dihydrostreptomycin both are secreted by way of the kidney, and renal insufficiency, therefore, raises the blood levels considerably above that found in patients with normal renal function, and causes increased ototoxicity.

Early in the course of the studies of dihydrostreptomycin and streptomycin ototoxicity, there was some disagreement about the location of the lesion. This author maintained in 1947 that because of the selectivity of the toxic effects for higher frequencies, the lesion is a peripheral one. It was, and it still is, difficult for me to see how a selective hearing loss in specific frequencies can be caused by any pathology proximal to the organ of Corti. I am happy to report that the to in a loud voice, however, and it became apparent that further research to determine the ototoxic effects of dihydrostreptomycin was needed With the cooperation of the tuberculosis department at the Gallenger hospital and the medical division of George Washington University in Washington, D C, the author conducted a study to determine the amount of hearing loss produced in patients treated with dihydrostreptomycin This study was reported in the *Annals of Otology, Rhinology and Laryngology* in 1951

On the basis of the results of these two studies, the following conclusions were drawn

*1* Dosages of 1 to 2 gms of streptomycin per day administered for periods of more than 45 to 50 days may produce complete loss of the labyrinthine function in many patients

*2* If the same regime as (1) is followed with dihydrostreptomycin, some 20 to 25 per cent of patients will sustain considerable hearing loss, particularly in the frequencies from 3000 to 8000 c p s

*3* Any patient receiving streptomycin and particularly dihydrostreptomycin should be tested routinely for changes in vestibular and auditory function If dihydrostreptomycin is used, the hearing tests should be continued for at least six to nine months after treatment has stopped, because many cases developed hearing losses after treatment had been discontinued

*4* Because streptomycin affects the vestibular system primarily, it should be the drug of choice Many patients will compensate for loss of vestibular function, but there is no satisfactory way to compensate for hearing loss

## LATER STUDIES

A review of the recent literature revealed that the conclusions stated above are still valid Reports by Anderson in the *Journal of Laryngology and Otology*, Lidén in *Acta Oto-laryngologica* Cawthorne in the *British Medical Journal*, and Hawkins et al in the *Antibiotics Annual* of 1956-57, confirm the results of studies made prior to 1953 There is

Prior to the therapy, each patient was tested in a quiet room with a standard audiometer at 500, 1000, 2000, 3000, 4000 and 6000 cycles per second He was then tested twice a week for four to six weeks during the early part of the study After this initial schedule was completed, each patient was tested once a week for approximately 90 to 100 days and then once every two weeks until discharged or lost to the study for one reason or another (see Table I)

TABLE I

Number of Audiograms Per Patient.

| No Patients | No Audiograms |
|---|---|
| 100 | 1103 |
| 17 | 6-12 |
| 19 | 18-26 |
| 14 | 28-58 |
| Least per patient | 6 |
| Most per patient | 58 |

TABLE II

Amount of Antibiotic Administered to Date of Report

| Patients treated with DHSM (N = 51) | | | Patients treated with DIDRO (N = 49) | |
|---|---|---|---|---|
| No with no shift | No with shift | No Grams | No with no shift | No with shift |
| 3 | 0 | 1-24 | 3 | 0 |
| 12 | 0 | 25-49 | 1 | 0 |
| 4 | 2 | 50-74 | 8 | 1 |
| 3 | 1 | 75-99 | 5 | 1 |
| 10 | 3 | 100-124 | 11 | 6 |
| 3 | 1 | 125-149 | 2 | 2 |
| 5 | 1 | 150-174 | 3 | 4 |
| 2 | 1 | 175-199 | 0 | 0 |
| 0 | 0 | 250-274 | 0 | 0 |
| 0 | 0 | 401 | 1 | 1 |
| 42 | 9 | | 34 | 15 |

Fifty-one of the patients received 1 gm of dihydrostreptomycin per day, and 49 received 1 gm of didrothenate per day Of the 51 patients receiving dihydrostreptomycin, nine showed an elevation in their auditory thresholds, and of the 49 patients receiving didrothenate, 15 showed an elevation in their auditory thresholds Table II shows how many of the general conclusion now is that the lesion is undoubtedly in the end-organ, both in the case of the vestibular apparatus and the hearing mechanism.

## RECENT DEVELOPMENTS

A recent report of great interest to those of us concerned with the ototoxicity of these antibiotics stated that when pantothenic acid is added to streptomycin or to dihydrostreptomycin, treatment is accompanied by less toxicity. Several German workers, Keller et al. in particular, reported in April, 1956, that considerably less toxicity resulted in animals treated with either streptomycin or dihydrostreptomycin in combination with pantothenic acid. Several studies were conducted in the United States, notably by Hawkins in 1956-57, to check the validity of the German claim. None of these studies confirmed the German conclusions

Much of the research into the effects of pantothenic acid combinations has been done with animals, particularly cats and mice Because it appeared that pantothenic acid combinations might be less toxic in animals, the Lederle Company, in cooperation with the Department of Medicine, University of California at Los Angeles, requested that a study be conducted under my supervision to compare in human subjects the effects of the pantothenic acid combination called didrothenate (DIDRO) with the effects of regularly available dihydrostreptomycin. It was agreed that tuberculous patients would be used and that equal numbers would be treated with standard dihydrostreptomycin and didrothenate specially prepared by Lederle for experimental purposes In this way the toxicity of the drugs could be compared under controlled conditions

## PRESENT STUDY.

A total of 149 patients started in the program, but only 100 of them are considered in this paper The remaining 49 patients were excluded from the analysis, because they were discharged from the hospital for one reason or another before they had received enough drug to be of use in the study

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| 4 | 2 | 50 74 | 8 | 1 |
| 3 | 1 | 75 99 | 5 | 1 |
| 10 | 3 | 100 124 | 11 | 6 |
| 3 | 1 | 125 149 | 2 | 2 |
| 5 | 1 | 150 174 | 3 | 4 |
| 2 | 1 | 175-199 | 0 | 0 |
| 0 | 0 | 250 274 | 0 | 0 |
| 0 | 0 | 401 | 1 | 1 |
| 42 | 9 | | 34 | 15 |

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Comparisons of the amount of threshold shift in db at 1000 c p s in the right ear show that two of the patients on dihydrostreptomycin acquired shifts of 5 to 15 db and five of those on didrothenate showed a similar threshold shift At 4000 c.p s in the right ear, one patient on dihydrostreptomycin and four on didrothenate showed a 5 to 15 db threshold shift

TABLE III

Number of Patients with Threshold Shifts of 5 15 db, 20 30 db, 35 50 db

| Threshold Shift (db) | Antibiotic | Ear | Number of patients with shift at indicated frequency (c p s) 500 | 1000 | 2000 | 3000 | 4000 | 6000 |
|---|---|---|---|---|---|---|---|---|
| 5 to 15 | DHSM | R | 3 | 2 | 2 | 1 | 1 | 1 |
| 5 to 15 | DHSM | L |  | 2 | 2 |  | 3 | 1 |
| 5 to 15 | DIDRO | R | 5 | 5 | 3 | 3 | 4 | 5 |
| 5 to 15 | DIDRO | L | 3 | 4 | 3 | 4 | 5 | 6 |
| 20 to 30 | DHSM | R |  |  | 1 |  |  | 2 |
| 20 to 30 | DHSM | L | 1 | 1 | 2 | 1 | 1 | 1 |
| 20 to 30 | DIDRO | R |  |  |  | 2 |  | 4 |
| 20 to 30 | DIDRO | L |  |  | 1 |  |  | 2 |
| 35 to 50 | DHSM | R |  |  | 1 | 2 | 1 | 1 |
| 35 to 50 | DHSM | L |  |  |  |  | 1 | 1 |
| 35 to 50 | DIDRO | R |  |  |  |  | 1 | 1 |
| 35 to 50 | DIDRO | L |  |  |  | 1 |  | 1 |

Threshold measurements of the left ears show that two of the patients on dihydrostreptomycin sustained from 5 to 15 db shift at 1000 c p s and four of those on didrothenate showed the same shift Again when the shifts are measured at 4000 c p s in the left ear, three of the patients on dihydrostreptomycin showed from 5 to 15 db shift and 5 of those on didrothenate had the same shift (see Fig 1)

At 1000 c p s only one of the 100 patients acquired a shift greater than 15 db on either drug At 4000 c p s none showed a shift of 20 to 30 db on either drug in the right ear In the left ear, however, one person treated with dihydrostreptomycin showed a shift of 20 to 30 db (see Fig 2), also at 4000 c p s, two of the patients on dihydrostreptomycin showed shifts of 35 to 50 db, one in the right ear and one in the left (see Fig 3)

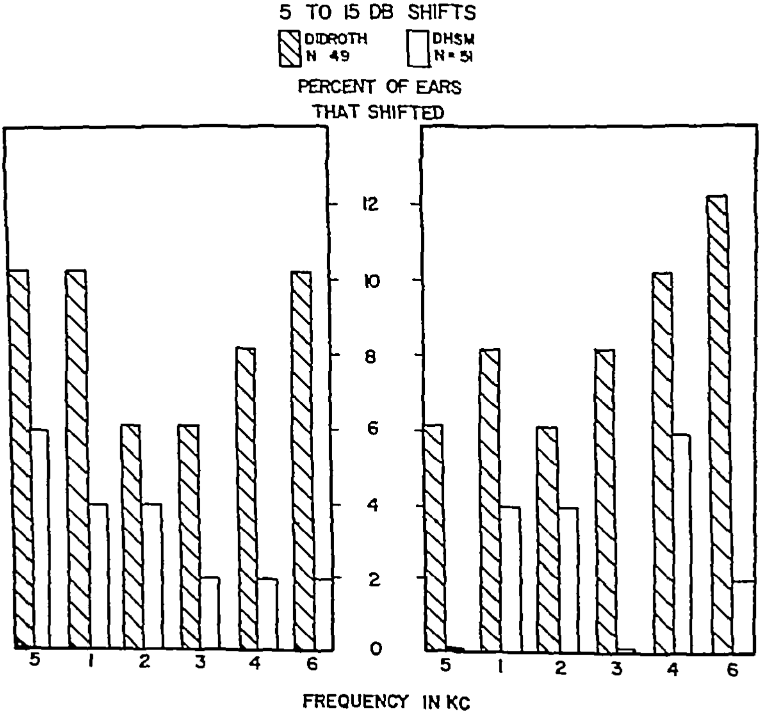

Fig 1

Threshold shifts were compared at 1000 and at 4000 c p s, because losses at 1000 c p s reflect the amount of handicap for communication by speech and losses at 4000 c p s represent the maximum losses usually found in the high frequencies

There were no threshold shifts at the speech frequencies in excess of 30 db when either antibiotic was used On the basis of this, we can assume that no patient will sustain a significant hearing loss as a result of treatment if he has normal persons in the total group exhibited an elevation in threshold, and the number of grams of dihydrostreptomycin or didrothenate the "shifters" had received Table III shows the number of persons who acquired threshold shifts of 5 to 15 db, 20 to 30 db, and 35 to 50 db, at each of the frequencies tested

Comparisons of the amount of threshold shift in db at 1000 c p s in the right ear show that two of the patients on dihydrostreptomycin acquired shifts of 5 to 15 db and five of those on didrothenate showed a similar threshold shift At 4000 c p s in the right ear, one patient on dihydrostreptomycin and four on didrothenate showed a 5 to 15 db threshold shift

TABLE III

Number of Patients with Threshold Shifts of 5 15 db, 20 30 db, 35-50 db

| Threshold Shift (db) | Antibiotic | Ear | Number of patients with shift at indicated frequency (c p s)<br>500 | 1000 | 2000 | 3000 | 4000 | 6000 |
|---|---|---|---|---|---|---|---|---|
| 5 to 15 | DHSM | R | 3 | 2 | 2 | 1 | 1 | 1 |
| 5 to 15 | DHSM | L | | 2 | 2 | | 3 | 1 |
| 5 to 15 | DIDRO | R | 5 | 5 | 3 | 3 | 4 | 5 |
| 5 to 15 | DIDRO | L | 3 | 4 | 3 | 4 | 5 | 6 |
| 20 to 30 | DHSM | R | | | 1 | | | 2 |
| 20 to 30 | DHSM | L | 1 | 1 | 2 | 1 | 1 | 1 |
| 20 to 30 | DIDRO | R | | | | 2 | | 4 |
| 20 to 30 | DIDRO | L | | | 1 | | | 2 |
| 35 to 50 | DHSM | R | | | 1 | 2 | 1 | 1 |
| 35 to 50 | DHSM | L | | | | | 1 | 1 |
| 35 to 50 | DIDRO | R | | | | | 1 | 1 |
| 35 to 50 | DIDRO | L | | | | 1 | | 1 |

Threshold measurements of the left ears show that two of the patients on dihydrostreptomycin sustained from 5 to 15 db shift at 1000 c p s and four of those on didrothenate showed the same shift Again when the shifts are measured at 4000 c p s in the left ear, three of the patients on dihydrostreptomycin showed from 5 to 15 db shift and 5 of those on didrothenate had the same shift (see Fig 1)

At 1000 c p s only one of the 100 patients acquired a shift greater than 15 db on either drug At 4000 c.p s none showed a shift of 20 to 30 db on either drug in the right ear In the left ear, however, one person treated with dihydrostreptomycin showed a shift of 20 to 30 db (see Fig 2), also at 4000 c p s, two of the patients on dihydrostreptomycin showed shifts of 35 to 50 db, one in the right ear and one in the left (see Fig 3)

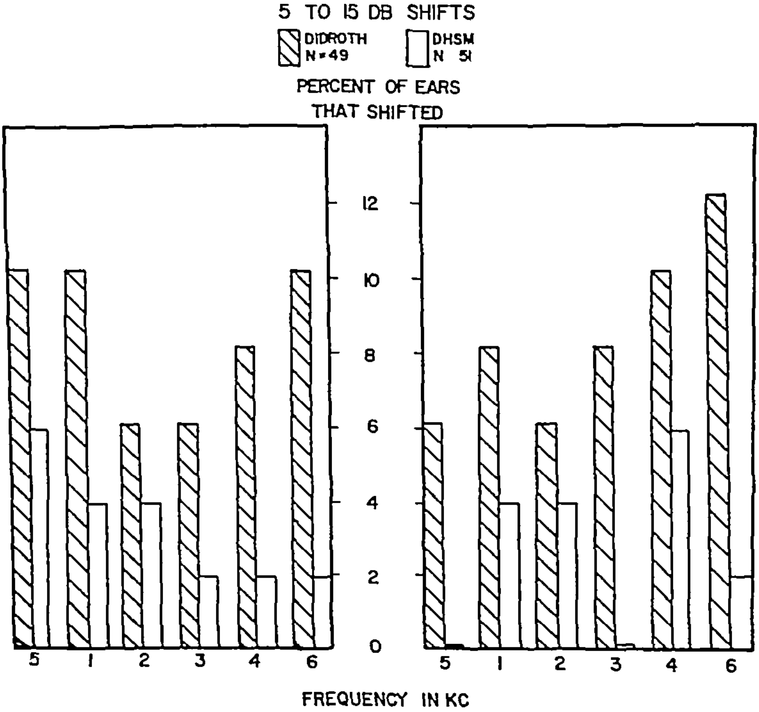

Fig 1

Threshold shifts were compared at 1000 and at 4000 c p s, because losses at 1000 c p s reflect the amount of handicap for communication by speech and losses at 4000 c p s represent the maximum losses usually found in the high frequencies

There were no threshold shifts at the speech frequencies in excess of 30 db when either antibiotic was used On the basis of this, we can assume that no patient will sustain a significant hearing loss as a result of treatment if he has normal hearing when the antibiotic is started Allowing for a reasonable amount of expected variation in audiometry, some 10 db , that is, we judge that only a relatively small per cent of the shifts are significant Only two ears on dihydrostreptomycin and one on didrothenate showed shifts greater than 10 db at 1000 c p s

At 4000 c p s , we find that only three ears in the didrothenate group show more than 10 db shift and that only five ears in the dihydrostreptomycin group show more than 10 db shift When reduced to percentage, these figures are 3 per cent and 4 9 per cent respectively

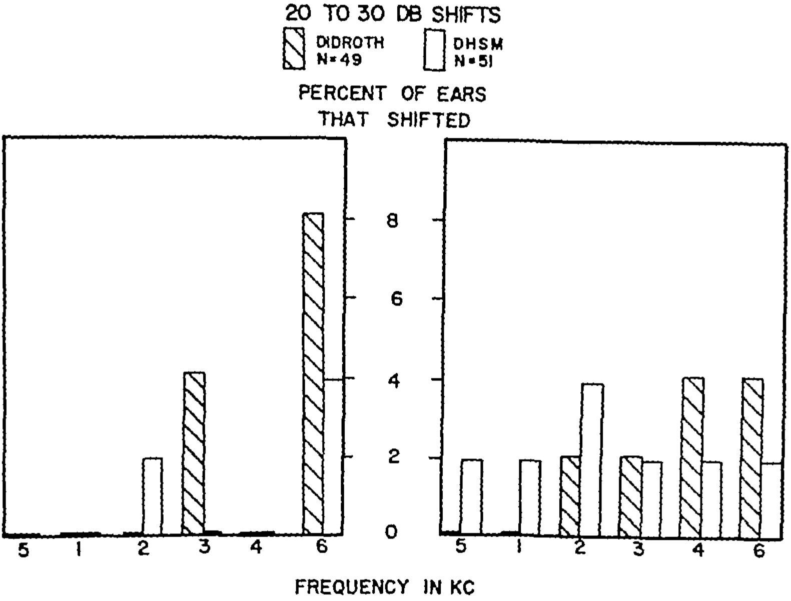

Fig 2

As for losses in excess of 30 db at 4000 c p s, we find that one ear shifted 40 db when didrothenate was used and when dihydrostreptomycin was used, one ear shifted 50 db, and another 40 db If all ears that shifted more than 10 db at any frequency are lumped together, there are 20 in the group treated with didrothenate and 23 in the group treated with dihydrostreptomycin If we look for ears showing losses greater than 30 db at any frequency, we find that there are only four with shifts of this magnitude in the group treated with didrothenate and eight in the group treated with dihydrostreptomycin (see Table III)

The significance of the magnitude of threshold shift to the patient must be evaluated from the final audiogram In other words, is the change in hearing level enough to cause handicap? Table IV shows the number of patients whose

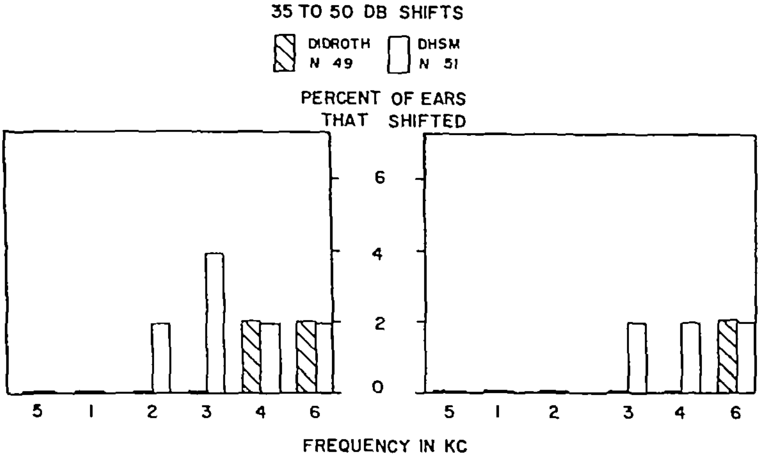

Fig 3

thresholds at 1000 and 4000 c p s lie between 5 to 15 db, 20 to 30 db, 35 to 50 db, 55 to 70 db, and above 75 db Only one ear shows a hearing level greater than 30 db at 1000 c p s This case was treated with dihydrostreptomycin

To assess the amount of handicap resulting from the hearing losses acquired during this study, let us compare the beginning hearing level with the final hearing level of ears that show less than 20 db at 1000 and 2000 c p s prior to treatment and more than 20 db at 1000 and 2000 c p s at the time of this report There is only one such case at 1000 c p s in both ears, three cases, two with bilateral losses, and one with a unilateral loss at 2000 c p s , in the group treated with dihydrostreptomycin In the group treated with didrothenate, we find no cases at 1000 c p s and at 2000 c p s , three cases with bilateral losses

Table V shows the number of grams of antibiotic administered to cases whose hearing level on the pre-treatment audiogram was less than 20 db at 1000 and 2000 c p.s and on the post-treatment audiogram was greater than 20 db Note the similarity in dosages of dihydrostreptomycin and didrothenate

TABLE IV

Final Threshold of Patients Showing an Elevation at 1000 and 4000 c p s

| Hearing Level in db | Antibiotic Used | Right Ear 1000 c.p s No Cases | Right Ear 4000 c p s No Cases | Left Ear 1000 c p s No Cases | Left Ear 4000 c p s No Cases |
|---|---|---|---|---|---|
| 5 15 | DHSM | 8 | 4 | 6 | 2 |
| 5 15 | DIDRO | 13 | 4 | 12 | 2 |
| 20 30 | DHSM | 3 | 2 | 4 | 1 |
| 20 30 | DIDRO | 2 |  | 3 | 2 |
| 35 50 | DHSM |  | 2 | 1 | 2 |
| 35 50 | DIDRO |  | 5 |  | 5 |
| 55 70 | DHSM |  | 3 |  | 2 |
| 55 70 | DIDRO |  | 4 |  | 4 |
| 75+ | DHSM |  |  |  | 3 |
| 75+ | DIDRO |  | 2 |  | 2 |

TABLE V

Amount of antibiotic used when threshold shift first appeared and total amount administered to date to patients whose thresholds at 1000 and 2000 c p s were less than 20 db pre treatment and more than 20 db post treatment

| Case | DHSM No Gms When Shift Started | Total Dose | Case | DIDRO No Gms When Shift Started | Total Dose |
|---|---|---|---|---|---|
| A | 125 | 186 | A | 19 | 150 |
| B | 42 | 54 | B | 168 | 258 |
| C | 130 | 138 | C | 46 | 84 |

Let us now consider an average of the post-treatment thresholds at 500, 1000 and 2000 c p s in the better ear If we assume than the hearing loss is significant when this average is 30 db or more, only one patient treated with dihydrostreptomycin and none treated with didrothenate showed a significant hearing loss (see Table VI)

## DISCUSSION

You will no doubt remember that we started out to determine whether, in a group of 100 tuberculous patients, didrothenate (the pantothenic acid salt of dihydrostreptomycin) exhibited less ototoxicity than did dihydrostreptomycin Let me hasten to make clear than 100 total cases in this kind of study are enough only to establish trends We cannot draw conclusions about the magnitude of hearing loss that will result from a given treatment The trends are quite clearly evident, however, and I feel sure that additional studies will confirm them

TABLE VI

Number of Patients with Significant Hearing Loss After Treatment (average of 30 db or more at 500 1000 and 2000 c.p.s )

| DHSM | DIDRO |
|---|---|
| 1 | 0 |

If we compare the two treatments generally on the basis of amount of shift produced, we find more patients with shifts greater than 30 db in the dihydrostreptomycin group Consider in more detail the magnitude of threshold shift in terms of the amount of antibiotic received by the patient The data in Table II indicate that out of 22 patients who received less than 100 gms of Dihydrostreptomycin, only three showed any increase in elevation of their auditory threshold These data also show that out of 17 patients who received less than 100 gms of dihydrostreptomycin, only two showed an increase in elevation of their auditory threshold There were 20 patients who received between 100 and 200 gms of dihydrostreptomycin and six showed an increase in threshold level Sixteen patients received between 100 and 200 gms of didrothenate and 12 showed an increase in threshold

These comparisons seem to indicate that didrothenate is more toxic than dihydrostreptomycin From Table III, however, you will note that most of the threshold shifts in the didrothenate treated group are 10 db or less That is, they fall within our arbitrary limits of expected audiometric variability and cannot, therefore, be related to ototoxicity Comparisons of magnitudes of shift would seem to indicate that dihydrostreptomycin is more toxic than didrothenate The apparent difference, however, could be due to the smaller amount of dihydrostreptomycin contained in didrothenate One gram of didrothenate contains less dihydrostreptomycin than one gram of pure dihydrostreptomycin

When the results of this study are compared with those of my 1951 study, there appears to be a marked change in ototoxicity of dihydrostreptomycin In spite of the larger daily dosage received by some of the patients in the earlier study, there are significant differences in the amount of threshold shift that indicate much less ototoxicity from the dihydrostreptomycin that is available today Specifically

*1* There were no cases of profound deafness in this series

*2* Only one case treated with dihydrostreptomycin and none treated with didrothenate had a final average hearing level greater than 30 db at 500, 1000 and 2000 c p s

*3* No positive conclusions can be drawn regarding vestibular effects, since no vestibular tests were performed There were no symptoms of vestibular dysfunction, however, and we assume that there were no significant vestibular changes

In contrast to these findings, the 1951 study included one case of profound deafness, also, out of the 40 cases treated with 1 gm of dihydrostreptomycin per day for periods comparable to those reported in this study, 14 or 35 per cent showed losses in excess of 30 db throughout the audiometric frequency range About half of the impaired hearing cases showed vestibular dysfunction symtomatically and with caloric tests

Why there is such an apparent decrease in dihydrostreptomycin ototoxicity is difficult to say It is possible that present day manufacturing processes produce a purer and, therefore, less toxic product, but the manufacturers have been questioned about this, and they are not aware of any changes in purity

In view of some recent reports, we might well ask ourselves whether today's dihydrostreptomycin really is less toxic During the past two or three years, there have been numerous oral and written reports of sudden increases in the auditory threshold of patients on small doses of dihydrostreptomycin, and combinations containing dihydrostreptomycin These small doses vary from 1 to 10 grams In light of our present study, it is difficult to explain these losses The facts seem to be in order, however, the losses are real and the causal relations appear well founded In my opinion, there can be only one explanation—individual sensitivity to dihydrostreptomycin Such sensitivity is not restricted to the mycin preparations We have known for many years that ototoxicity may result from quinine, aspirin, nicotine, etc. It is not unreasonable to assume that with more widespread general use of streptomycin and dihydrostreptomycin singly and in combination with broad spectrum preparations, we will be treating an increasing number of susceptible individuals

## CONCLUSIONS

The conclusions that I wish to draw from this study are

*1* A comparison of hearing losses produced in patients treated with didrothenate and patients treated with dihydrostreptomycin definitely shows that didrothenate is not significantly less toxic than dihydrostreptomycin

*2* When the results of this study are compared with the results of previous studies, not only is the number of persons who show an elevation of threshold smaller in this study, but also the amount of threshold shift is considerably less

*3* When compared with my previous investigations the results of this study indicate that now larger total doses of these antibiotics can be administered before an elevation in the auditory threshold level appears

4. Streptomycin is still the preferable antibiotic. It is better to lose vestibular function than to lose auditory function.

## SUMMARY

Audiometric data from tests of 100 tuberculous patients treated with dihydrostreptomycin and didrothenate (the pantothenic acid salt of dihydrostreptomycin) are presented. Fifty-one of the 100 cases received 1 gm. of dihydrostreptomycin per day and 49 received 1 gm. of didrothenate per day. Nineteen of the patients received total doses of 25 to 99 gms. of dihydrostreptomycin, 14 of them received 25 to 99 gms. of didrothenate. Twenty of these patients received 100 to 199 gms. of dihydrostreptomycin. Sixteen of them received 100 to 199 gms. of didrothenate. One received 258 gms. of didrothenate and another 401 gms. of didrothenate. One person in the dihydrostreptomycin group showed a clinically significant hearing loss. There were no clinically significant losses in the didrothenate group. The majority of threshold shifts occurred at frequencies above 2000 c.p.s.

## RECOMMENDATIONS

Five important precautions that can be used to safeguard against dihydrostreptomycin toxicity are:

1. Where either dihydrostreptomycin or streptomycin is indicated, streptomycin should be used. There is no contraindication to this procedure. Dihydrostreptomycin has never been shown to be better therapeutically.

2. When broad spectrum antibiotics are used in combination with streptomycin or dihydrostreptomycin, the combination used should contain streptomycin, not dihydrostreptomycin.

3. The manufacturers of combined antibiotics should be required to state clearly which antibiotics are contained in the combination preparations.

4. Where long term treatment with streptomycin is contemplated, vestibular and auditory tests should be given routinely

5 When short term treatment is contemplated, that is, less than a total of 10 gms to be administered over a period of five to ten days, the treatment should be discontinued at the first sign of vestibular or auditory toxicity Tinnitus and slight vertigo are significant

## ACKNOWLEDGMENTS

This study was made possible by a grant from the Lederle Company I thank Dr William Hewitt, Department of Medicine, U C L A School of Medicine, and Dr Stanton Hardy of the Lederle research staff for their help on this project I also thank Mr Andrell Henry, the audiologist, who did most of the hearing tests

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# SEVENTH INTERNATIONAL CONGRESS OF BRONCHOESOPHAGOLOGY

The Seventh International Congress of Bronchoesophagology will be held at Kyoto (Japan) University, September 12-14, 1958, under the direction of Prof Mituharu Goto, M D , Otorhinolaryngological Clinic, Kyoto University Hospital, Kyoto, Japan

A registration fee of $25 00 U S A. will be charged all physicians and a fee of $10 00 for wives or non-medical guests Registered members are admitted free to banquet, receptions and sightseeing tours

# FOUR UNUSUAL CASES OF TEMPORAL BONE DISEASE *

DAVID D DEWEESE, M D ,

Portland, Ore

Review of the recent otolaryngologic literature reveals only one case report of infection of the petrous portion of the temporal bone Lest we forget that this condition still occurs, I am presenting three cases, which I believe, emphasize the principal symptoms produced by disease in this region

The fourth case is not one of temporal bone infection, nevertheless, it is presented because not only the area involved but also the circumstances of the involvement are unusual

## CASE REPORTS

*Case 1* A man aged 63 was first seen on June 2 1954, because of discharge from the right ear double vision, and dizziness

Symptoms began seventeen days prior to admission First, he had pain in the right ear Several hours later there was a bloody discharge from the ear He was hospitalized and given terramycin and penicillin intramuscularly This relieved the pain but the ear continued to drain Twelve days prior to admission he became aware of double vision and of dizziness There was no other contributory history

Examination of the nose, throat, nasopharynx, larynx and left ear was normal The right ear showed a pulsating, purulent discharge from a central perforation of the eardrum The eardrum was thick and pink but not bulging The mastoid was tender

On general physical examination the patient was well oriented He had complete lateral rectus paralysis in the right eye There was partial paralysis of the VIIth nerve of a peripheral type There was nystagmus to the left The neck was not stiff Temperature was 99 5 degrees

Leukocyte count was 11 500 Roentgenogram of the mastoid showed some sclerosis with definite decalcification of the intercell walls, in addition, there was erosion of the inner table of the petrous ridge on the right side Chest roentgenogram was normal

He was hospitalized and given heavy doses of penicillin The following day a radical mastoidectomy and petrous exploration were done The mastoid portion of the temporal bone was the seat of active subacute purulent infection with cell destruction There was no erosion of the

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*Read at the meeting of the Western Section American Laryngological Rhinological and Otological Society Inc Beverly Hills Calif Jan 18 1958

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labyrinth Healing granulations were present over one area of the sigmoid sinus Posterior to the labyrinth there was a tract of cells A similar tract of cells was present inferior to the labyrinth It was possible to enter the body of the petrous superior to the labyrinth In this area there was inflammatory tissue and soft bone, but no frank pus

Postoperative recovery was somewhat slower than is usual after radical mastoidectomy but except for slight fever in the afternoon he was up oriented eating, and appeared well On June 13 (ten days postoperatively) he suddenly became semi-comatose then comatose Fever rose to 103 degrees There were no localizing signs

A neurosurgical consultant followed him for four days On the fourth day flaccid paralysis appeared in the left arm and left leg Babinski was positive. The neck was stiff but not rigid There was no papill edema. Leukocyte count was normal Spinal fluid showed a mild increase in protein and 75 cells all of which were lymphocytes

In view of these findings the patient was taken to the operating room for the second time (June 17) The old mastoid incision was reopened after which the petrous was again examined A wide examination was also made of the dura of the middle as well as the posterior cranial fossa The dura was normal Under the same anesthetic a neurosurgeon opened the right temporal area and probed the temporal lobe to see if there was an abscess None was found

Patient s condition following operation remained poor 48 hours later he expired

Autopsy showed a healing mastoid petrous wound There was no evidence of brain abscess Three areas of malignant metastases were found one over the midline of the dura on the left side the second deep in the cerebellum near the dentate nucleus and the third in the left side near the surface of the temporal cortex Both adrenal glands were filled with metastatic carcinoma There was no evidence of malignancy in the mastoid or the petrous The primary lesion was presumably a small carcinoma in the medial portion of the left lung lying immediately behind the heart. Recheck of the chest roentgenogram taken preoperatively failed to reveal the lesion

*Case 2* A woman aged 33 was first seen on January 26 1956 because of persistent headache on the right side discharge from the right ear and low grade fever

She stated she had had draining from the right ear since she was 18 months old Eleven years prior to admission after swimming the ear became painful and the discharge increased A diagnosis of acute mastoiditis was made and a partial mastoidectomy (whatever that is) was performed Following this operation the ear continued to drain and she had intermittent pain in the ear

Three years prior to admission she began to have a low grade fever and the discomfort in the ear increased A radical mastoidectomy was performed at that time The ear healed Occasionally she had discharge from the ear for periods of 24 or 48 hours but without pain

One month prior to admission she had severe headache on the right side and nausea This was followed by increased discharge from the ear without pain Ten days prior to admission she had difficulty in focusing the eyes and there was some blurring of vision The headache also recurred and she had a low grade fever of between 99 and 100 degrees She stated that when she was quiet she was fairly comfortable but when she was sitting up or walking the headache was severe She was unable to read print except for a few minutes She denied double

vision Leaning or turning to the left produced nausea without vomiting In addition to the headache she had a pain which she described as deep aching behind the right eye

On examination the throat, nose, and left ear were normal The right ear showed a clean radical mastoid cavity, in which all structures were visible The round window, the oval window with the stapes bound down, and the intratympanic course of the facial nerve were clearly visible There was some moisture in the region of the Eustachian tube There was a small area of exposed bone behind the labyrinth Suctioning of the middle ear area produced slight dizziness and nystagmus The fistula test was negative

Blood count was normal Roentgenograms showed the previous surgical defect. In the apex of the petrous the cells were clouded without definite bone destruction

Neurologic examination was entirely normal except that the neurologist felt the history indicated definite meningeal irritation An electroencephalogram was reported as abnormal because of isolated slow waves which arose in both hemispheres, but more so on the right Extraocular muscle function, visual fields, and fundi were normal

A diagnosis of petrositis was made, and operation was advised

Exploration of the right temporal bone was done on January 30, 1956 The previously described mastoid cavity was clean, except for pus in one tract of cells immediately superior to the intratympanic course of the facial nerve and in another tract of cells behind the labyrinth Exploration of the postlabyrinthine tract failed to reveal anything unusual There was a wide space of pneumatization superior to the superior semicircular canal making it possible to explore the petrous deeply under direct vision The bone of the body of the petrous was granular and soft There was granulation tissue in most of the body of the petrous to the apex This was removed

After operation the headache disappeared Visual disturbance also disappeared She was discharged eight days postoperatively Except that the cavity was slow healing she did well for six weeks and then symptoms recurred Over the next three months she had intermittent headache and intermittent blurring of vision Then all symptoms subsided

Ten months postoperatively she began to have fever, which slowly increased to 102 degrees There was also recurrence of retro ocular pain In addition she had some chilly sensation but no real shaking chills Examination at this time showed the ear to be moist All other studies, including neurologic examination were within normal limits

She was carefully followed for one month During this period the temperature ranged from 99 5 to 102 degrees The only complaints otherwise were a feeling "as though I were being pulled over backwards" and increasing drowsiness

Because of the fever and other symptoms as well as the persistent discharge the temporal bone was again explored on November 23 1956, 11 months after the first exploration In the angle between the superior semicircular canal and the middle fossa dura a piece of sequestrated bone was found The petrous body and apex were again filled with soft granular bone which had the appearance of proliferative osteomyelitis This was removed The inner table of the roof of the petrous was removed toward the tip until solid bone was encountered in all directions Although the nerve could not be identified the internal auditory meatus must have been approached since there was twitching of the face Fur

ther removal of bone was discontinued A small polyethelene tube was placed in the petrous tip, and brought out into the mastoid cavity

The tube was slowly removed over a period of six weeks Penicillin and chloromycetin were used continuously throughout hospitalization and for six weeks after discharge The ear healed primarily Since that time the patient has been clinically well and symptom free

*Case 8* A man aged 49 was first seen on June 28 1955 His chief complaint was progressive hearing impairment in both ears of three years duration

He stated that during examination in 1952 his attention was called to the fact that the right side of his face appeared to be weak There was, however no paralysis He gave no history of tinnitus or dizziness

Examination of the nose throat nasopharynx and larynx was normal The palate rose normally The tongue and vocal cords moved normally There was weakness of all branches of the VIIth nerve on the right side The corneal reflexes were normal The left ear was entirely normal The right eardrum was intact *Through the eardrum* a small white area was visible anterior to the short process of the malleus

The audiogram was normal up to 2 000 cycles per second There was a high tone loss of hearing in both ears somewhat worse on the *left* side

Roentgenograms of the mastoid the skull and the internal auditory meatuses were normal Electrical tests of the right facial nerve showed equal chronaxie on both sides but elevation of the voltage required and of rheobase on the right side

A presumptive diagnosis of neuroma of the facial nerve was made and exploration advised The patient returned to his original physician who advised strongly against any type of operation on the ear

Seven months later on February 7 1956 he came back for re-examination In this interval his face had gradually become more paralyzed His eye was tearing He had had some paresthesias of the right side of the tongue and one or two momentary spells of true vertigo

Examination showed a definite small white mass which was pushing Shrapnel s membrane out in front of the malleus Electrical testing of the right VIIth nerve gave results identical with those obtained by testing seven months previously A complete neurologic examination was otherwise normal

This time the patient accepted advice for surgical exploration but operation was not performed until June 6 1956 The mastoid was normal and well pneumatized The antrum was normal After removal of the bony bridge over the aditus it became evident that the attic was full of a mass which appeared to be cholesteatoma The incus and head of the malleus were removed The horizontal semicircular canal was prominent There was no evidence of a superior semicircular canal The normal position of the superior semicircular canal was occupied by a large cholesteatoma which filled the medial part of the attic It extended underneath the intratympanic portion of the facial nerve as well as over the labyrinth and on top of the body of the petrous An area of the inner table was eroded and the dura was exposed for an area one-and a half cm in diameter in the floor of the middle fossa medial to the labyrinth The intratympanic course of the facial nerve had been completely exposed by the cholesteatoma All of the cholesteatoma was removed and the facial nerve was decompressed to the stylomastoid foramen

The pathologic report confirmed the clinical diagnosis of cholesteatoma

Postoperatively the radical mastoid cavity healed normally Because of

vision Leaning or turning to the left produced nausea without vomiting In addition to the headache she had a pain which she described as deep aching behind the right eye

On examination, the throat, nose, and left ear were normal The right ear showed a clean radical mastoid cavity, in which all structures were visible The round window, the oval window with the stapes bound down, and the intratympanic course of the facial nerve were clearly visible There was some moisture in the region of the Eustachian tube There was a small area of exposed bone behind the labyrinth Suctioning of the middle ear area produced slight dizziness and nystagmus The fistula test was negative

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The pathologic report confirmed the clinical diagnosis of cholesteatoma

Postoperatively the radical mastoid cavity healed normally Because of

vision Leaning or turning to the left produced nausea without vomiting In addition to the headache she had a pain which she described as deep aching behind the right eye

On examination the throat, nose, and left ear were normal The right ear showed a clean radical mastoid cavity, in which all structures were visible The round window the oval window with the stapes bound down, and the intratympanic course of the facial nerve were clearly visible There was some moisture in the region of the Eustachian tube There was a small area of exposed bone behind the labyrinth Suctioning of the middle ear area produced slight dizziness and nystagmus The fistula test was negative

Blood count was normal Roentgenograms showed the previous surgical defect In the apex of the petrous the cells were clouded without definite bone destruction

Neurologic examination was entirely normal except that the neurologist felt the history indicated definite meningeal irritation An electroencephalogram was reported as abnormal because of isolated slow waves which arose in both hemispheres, but more so on the right Extraocular muscle function visual fields, and fundi were normal

A diagnosis of petrositis was made, and operation was advised

Exploration of the right temporal bone was done on January 30, 1956 The previously described mastoid cavity was clean, except for pus in one tract of cells immediately superior to the intratympanic course of the facial nerve and in another tract of cells behind the labyrinth Exploration of the postlabyrinthine tract failed to reveal anything unusual There was a wide space of pneumatization superior to the superior semicircular canal making it possible to explore the petrous deeply under direct vision The bone of the body of the petrous was granular and soft There was granulation tissue in most of the body of the petrous to the apex This was removed

After operation the headache disappeared Visual disturbance also disappeared She was discharged eight days postoperatively Except that the cavity was slow healing, she did well for six weeks and then symptoms recurred Over the next three months she had intermittent headache and intermittent blurring of vision Then all symptoms subsided

Ten months postoperatively she began to have fever, which slowly increased to 102 degrees There was also recurrence of retro-ocular pain In addition, she had some chilly sensation but no real shaking chills Examination at this time showed the ear to be moist All other studies, including neurologic examination were within normal limits

She was carefully followed for one month During this period the temperature ranged from 99 5 to 102 degrees The only complaints otherwise were a feeling "as though I were being pulled over backwards" and increasing drowsiness

Because of the fever and other symptoms as well as the persistent discharge the temporal bone was again explored on November 23, 1956 11 months after the first exploration In the angle between the superior semicircular canal and the middle fossa dura a piece of sequestrated bone was found The petrous body and apex were again filled with soft granular bone which had the appearance of proliferative osteomyelitis This was removed The inner table of the roof of the petrous was removed toward the tip until solid bone was encountered in all directions Although the nerve could not be identified the internal auditory meatus must have been approached since there was twitching of the face Fur

ther removal of bone was discontinued A small polyethelene tube was placed in the petrous tip, and brought out into the mastoid cavity

The tube was slowly removed over a period of six weeks Penicillin and chloromycetin were used continuously throughout hospitalization and for six weeks after discharge The ear healed primarily Since that time the patient has been clinically well and symptom free

*Case 3* A man aged 49 was first seen on June 28 1955 His chief complaint was progressive hearing impairment in both ears of three years duration

He stated that during examination in 1952 his attention was called to the fact that the right side of his face appeared to be weak There was however no paralysis He gave no history of tinnitus or dizziness

Examination of the nose throat, nasopharynx and larynx was normal The palate rose normally The tongue and vocal cords moved normally There was weakness of all branches of the VIIth nerve on the right side The corneal reflexes were normal The left ear was entirely normal The right eardrum was intact *Through the eardrum* a small-white area was visible anterior to the short process of the malleus

The audiogram was normal up to 2 000 cycles per second There was a high tone loss of hearing in both ears somewhat worse on the *left* side

Roentgenograms of the mastoid the skull and the internal auditory meatuses were normal Electrical tests of the right facial nerve showed equal chronaxie on both sides but elevation of the voltage required and of rheobase on the right side

A presumptive diagnosis of neuroma of the facial nerve was made and exploration advised The patient returned to his original physician, who advised strongly against any type of operation on the ear

Seven months later on February 7 1956 he came back for re-examination In this interval his face had gradually become more paralyzed His eye was tearing He had had some paresthesias of the right side of the tongue and one or two momentary spells of true vertigo

Examination showed a definite small white mass which was pushing Shrapnel s membrane out in front of the malleus Electrical testing of the right VIIth nerve gave results identical with those obtained by testing seven months previously A complete neurologic examination was otherwise normal

This time the patient accepted advice for surgical exploration but operation was not performed until June 6 1956 The mastoid was normal and well pneumatized The antrum was normal After removal of the bony bridge over the aditus it became evident that the attic was full of a mass which appeared to be cholesteatoma The incus and head of the malleus were removed The horizontal semicircular canal was prominent There was no evidence of a superior semicircular canal The normal position of the superior semicircular canal was occupied by a large cholesteatoma which filled the medial part of the attic It extended underneath the intratympanic portion of the facial nerve as well as over the labyrinth and on top of the body of the petrous An area of the inner table was eroded and the dura was exposed for an area one-and a half cm in diameter in the floor of the middle fossa medial to the labyrinth The intratympanic course of the facial nerve had been completely exposed by the cholesteatoma All of the cholesteatoma was removed and the facial nerve was decompressed to the stylomastoid foramen

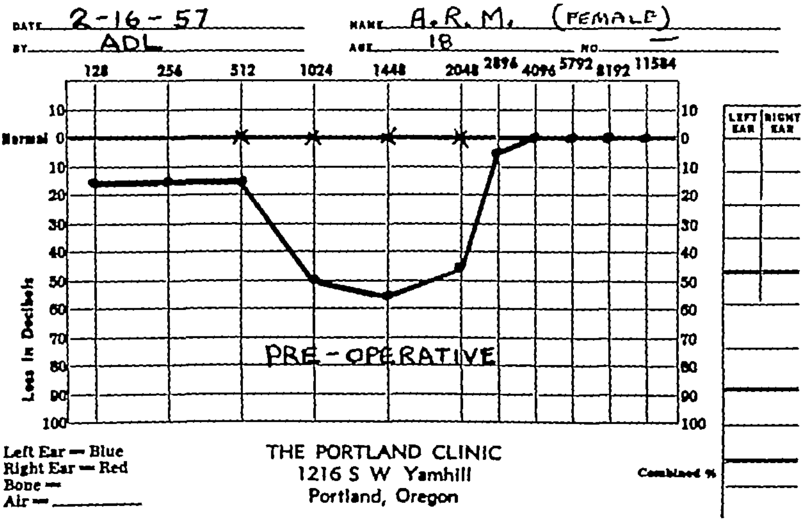
The pathologic report confirmed the clinical diagnosis of cholesteatoma

Postoperatively the radical mastoid cavity healed normally Because of

the facial paralysis which became complete electrical treatments were carried out daily Two and a half months postoperatively slight motion of the nasalus muscle was suspected This was more definite by the end of four and a half months

The patient was not seen again until June 21, 1957 approximately one year after operation Examination showed definite motion of all branches of the right facial nerve except the frontalis The patient said he had noticed beginning motion in March of 1957 He also said that on occasions he had had a momentary feeling of propulsion, but no real vertigo

Audiograms at this time showed 50 decibels loss of hearing up to 1 500 cycles per second There was a sharp drop above that to 100 db loss at 6,000 cycles per second



*Case 4* A girl, aged 18 was examined on February 16, 1957, because of hearing loss and low pitched buzzing tinnitus

Seven months prior to admission on July 21, 1956 she had been the guest passenger in the front seat of a car An accident occurred during which she was thrown forward and hit the left side of her head against the dashboard There was no facial laceration or unconsciousness The left ear bled some, but it was not treated

She noted loss of hearing in the left ear immediately after the accident, and for one week after the accident she had a loud buzzing tinnitus This improved somewhat but a low pitched buzzing tinnitus persisted There had been no vertigo at any time She denied past ear disease, and claimed entirely normal hearing prior to the accident, however, she had never had the hearing tested

Examination disclosed no abnormalities except for the left ear The eardrum on this side appeared to be slightly retracted The incudostapedial joint was visible through the drum and appeared to be in normal position The above audiogram of the left ear showed

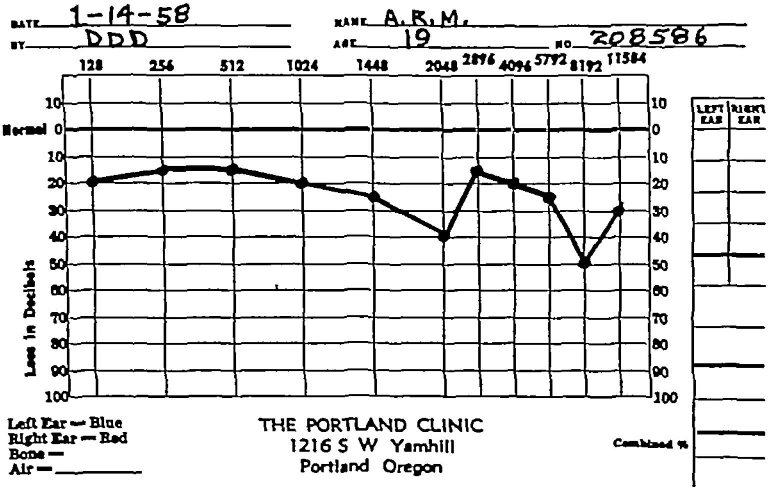
This is a pure conductive hearing loss Inflation of the Eustachian

tube on the left side produced only a 10 decibel improvement at 1 500 cycles and a 5 db improvement at 2 000 cycles With both 500 and 1 000 cycle tuning forks the Weber test was constantly lateralized to the left ear even when the right external auditory canal was occluded The Rinné test was negative on the left side with both forks These tests had been done previously by two other otolaryngologists

Roentgenograms of the mastoid showed normal well areated temporal bones on both sides

A diagnosis of probable dislocation of the incus was made

On March 27 1957 eight months after the injury exploratory operation was performed Since it was anticipated that the incus might have to be removed the middle ear was approached through the postaural incision Enough mastoid cells were removed to permit easy visualization of the middle ear There was a large zygomatic extension of air cells which made it possible to expose the attic of the middle ear without disturbing the soft tissue of the external auditory canal or the eardrum



DATE 1-14-58
BY DDD
NAME A.R.M.
AGE 19
NO 208586

Careful removal of the inner quarter of the bony external canal down to the *horizontal semicircular canal* allowed visualization of the ossicles The incudo-malleolar joint appeared to be normal The superior malleolar ligament was normal The incus was completely dislocated from the stapes Directed anteriorly it was holding the stapes partially fixed however there was some mobility of the stapes Since it was not possible to replace the incus on the head of the stapes so that it would remain it was therefore removed The cavity was closed

The above audiogram of the left ear taken on January 14 1958 ten months postoperatively, showed

The result is best stated in the patient s words 'I hear 100 per cent better and I notice it mostly in conversation '

Although the final hearing result is not normal it falls in the range of better than 25 db in all speech tones except those of 2 000 cycles per the facial paralysis which became complete, electrical treatments were carried out daily Two and a half months postoperatively slight motion of the nasalus muscle was suspected This was more definite by the end of four and a half months

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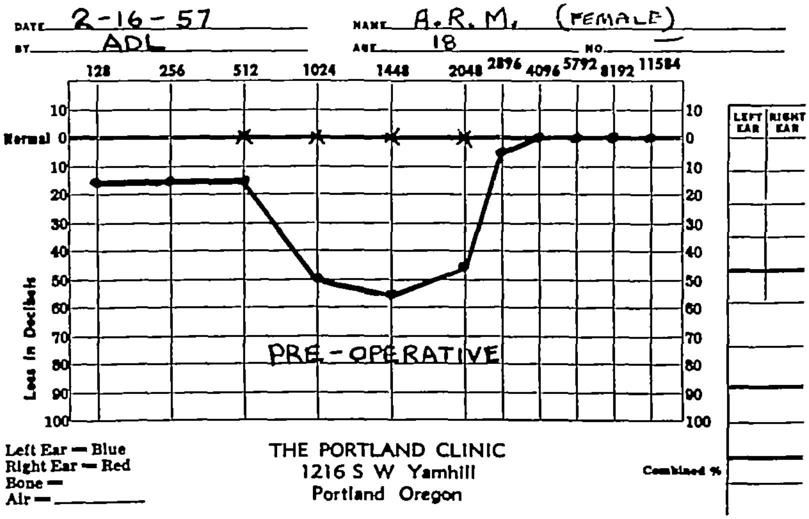

DATE 2-16-57
BY ADL
NAME A.R.M. (FEMALE)
AGE 18
NO. —

THE PORTLAND CLINIC
1216 S W Yamhill
Portland Oregon

*Case 4* A girl aged 18, was examined on February 16 1957, because of hearing loss and low pitched buzzing tinnitus

Seven months prior to admission on July 21, 1956 she had been the guest passenger in the front seat of a car An accident occurred during which she was thrown forward and hit the left side of her head against the dashboard There was no facial laceration or unconsciousness The left ear bled some, but it was not treated

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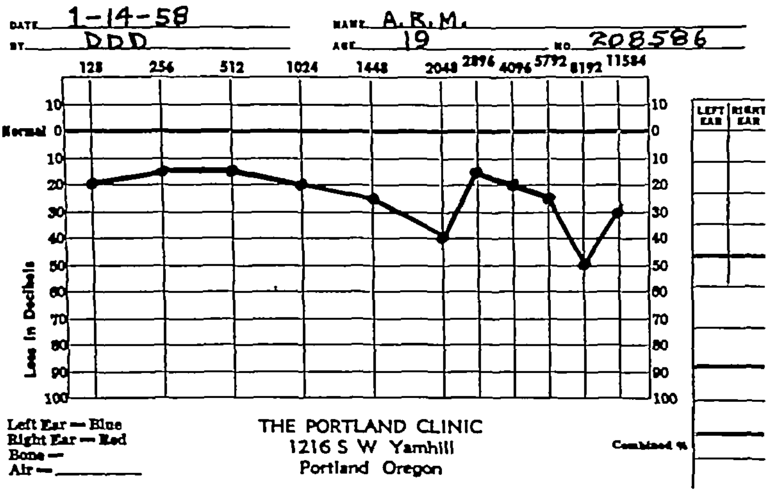

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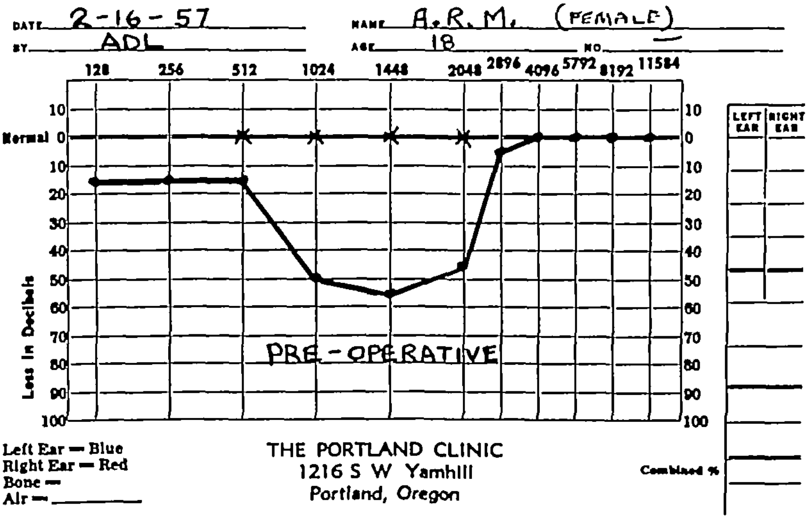

DATE 2-16-57 NAME A.R.M. (FEMALE)
BY ADL AGE 18 NO. —

Left Ear — Blue
Right Ear — Red
Bone —
Air —

THE PORTLAND CLINIC
1216 S W Yamhill
Portland, Oregon

*Case 5* A girl, aged 18 was examined on February 16 1957 because of hearing loss and low pitched buzzing tinnitus

Seven months prior to admission on July 21, 1956, she had been the guest passenger in the front seat of a car An accident occurred, during which she was thrown forward and hit the left side of her head against the dashboard There was no facial laceration or unconsciousness The left ear bled some, but it was not treated

She noted loss of hearing in the left ear immediately after the accident, and for one week after the accident she had a loud buzzing tinnitus This improved somewhat but a low pitched buzzing tinnitus persisted There had been no vertigo at any time She denied past ear disease and claimed entirely normal hearing prior to the accident, however, she had never had the hearing tested

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One case of dislocation of the incus is also reported Surgical removal of this bone was followed by clinically useful hearing

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1 DAY, KENNETH M A Primary Cholesteatoma of the Middle Ear Case Report *Ann Otol, Rhinol and Laryngol*, 64 161-163 March, 1955

1216 S W Yamhill Street

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## INSTITUTE ON INDUSTRIAL DEAFNESS

Colby College, Waterville, Maine, presents the Sixth Annual Institute on Industrial Deafness, August 11-20 inclusive Please note that the course has been extended for three days in order to include engineering for noise control Its objective will be to train physicians interested in the problem, nurses, plant engineers and others in initiating and conducting hearing conservation programs in noisy industries The course includes basic otology, audiometry, noise measurement, ear protection and methods of noise control Class is limited to approximately twenty participants

The fee for the course is $250 and includes tuition, room and board The first week will constitute a complete course for doctors and nurses, and the reduced fee for this will be $200 Application should be made to Mr William A. Macomber, Colby College, Waterville, Maine second These findings would tend to confirm the stated opinion of others that serviceable hearing is possible without the ossicular chain They also support the feeling that an intact ossicular chain is responsible for 20 to 25 decibels of hearing

Speech reception threshold was recorded at 26 28 decibels Tolerance to loud sound was normal Ninety decibels of sound, pure tone, and white noise were not uncomfortable

## COMMENT

The variation in the histories of the first three patients emphasizes the different symptoms and signs which can be produced by disease of the petrous portion of the temporal bone These are annoying recurrent pain, usually behind the eye, persistent aural discharge, paralysis of the VIth and VIIth nerves, meningeal irritation, vertigo

The first patient had all symptoms and signs except retro-ocular pain The second had all signs except VIth and VIIth nerve paralysis, but there were signs of ease of ocular muscle fatigue The third patient showed only VIIth nerve paralysis and mild, nondiagnostic vertigo

Roentgenograms of the petrous (Stenver's and base plates) gave valuable information in two of the patients These are necessary additions to routine mastoid films when any deep involvement is suspected

The case of primary cholesteatoma is interesting because it is rare As in a similar case, reported by Dr Kenneth Day,[1] the mastoid portion of the temporal bone was normally pneumatized

Exploration and drainage of pus or removal of diseased bone is essential to successful recovery when the petrous is involved It is, therefore, evident that the otolaryngologist must constantly review the anatomy of the deep temporal bone Antibiotics alone are not the answer

## SUMMARY

Three cases of disease of the petrous portion of the temporal bone are presented Despite the rarity of petrositis, it points up the necessity of constant review of the anatomy of the deep temporal bone

One case of dislocation of the incus is also reported Surgical removal of this bone was followed by clinically useful hearing

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# EXPERIMENTAL OBSERVATIONS ON SQUAMOUS METAPLASIA OF THE TRACHEA*†

NOBLE O CORRELL, M D ,
and
EDWARD J BEATTIE, JR , M D ,
(By Invitation),
Chicago, Ill

## INTRODUCTION

In 1955 we began studies of the physiology of the trachea[1] Since much of the research on respiratory epithelium has been accomplished by otolaryngologists we felt that our findings might be of interest to this group

## REVIEW OF THE LITERATURE

More than 25 years ago there had been numerous observations on the physiology of the epithelium of the respiratory passages, by several different investigators[3,4,9,10,11]

In 1956, Hilding published a series of four articles on cigarette smoking, bronchial carcinoma and ciliary action[5,6,7,8] Proetz has also made numerous substantial contributions to the understanding of the physiology of respiratory epithelium[12,13] A complete review of the above literature in this paper is not possible nor necessary

We were interested in knowing whether the direction of beat of the cilia was inherent within the cell or due to some other factor We also wanted to know whether an autogenous devascularized free tracheal graft would survive, and if so, how the epithelium regenerated

In both dogs and chickens it was possible to excise two-

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*Read at the meeting of the Middle Section of the American Laryngological Rhinological and Otological Society Inc Chicago Ill Jan 13 1958

†From the Surgical Research Laboratories Presbyterian-St. Luke's Hospital and the University of Illinois School of Medicine Chicago Ill

Editor's Note This manuscript received in The Laryngoscope Office and accepted for publication March 10 1958

inch segments of the cervical trachea and anastomose the devascularized autogenous tracheal segment in a reversed direction, so that the cilia of the graft pointed caudad Those animals and birds which survived were killed and autopsied after variable periods The trachea, including the graft, was excised, fixed and stained for histological examination

The graft showed ischemic degenerative changes throughout the first 12 days During this period the only remnant of the epithelium was islands of reserve cells which were always in evidence Approximately two weeks following the reversal of the graft, revascularization could be seen in the sub-mucosal stroma, and by three weeks the normal ciliated epithelium had completely regenerated from the surviving islands of cuboidal type reserve cells

It was demonstrated that the cilia of the reversed tracheal graft retain their direction of beat with respect to the graft, thus propelling the overlying mucus stream caudad

An incidental finding during these experiments was that in the dog, the circumferential tracheal anastomoses tended to stricture Such a tendency could be discouraged by rotating the graft so that the membranous portions of the graft and trachea did not meet This purposeful rotational mal-alignment resulted in a ring of solid cartilage at the anastomotic sites which resisted stenosis

The chickens, having complete cartilaginous rings without a membranous portion, showed no tendency toward stricture of their tracheal anastomoses

Another incidental finding was that the birds and animals with reversed tracheal grafts always carried a ring of mucus at the caudad anastomosis, where it was continuously being piled up by the cilia These creatures were forced to cough at regular intervals to clear their mucus accumulations

The proximal anastomosis was always dry and underwent squamous metaplasia When the anastomoses were excised and the ends re-approximated, squamous metaplasia again occurred at the site of the proximal anastomosis This find-

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The work just described has been previously reported[1,2]

## METHODS

Four dogs were allowed to live longer than one year after their tracheal graft reversals Two dogs were killed on their 400th post-operative day They were autopsied and their tracheal grafts, including the anastomoses, were prepared for histological examination Two dogs were given permanent tracheostomies, bringing the cricoid cartilage out as a tracheal stoma on their 450th and 500th post reversal day respectively

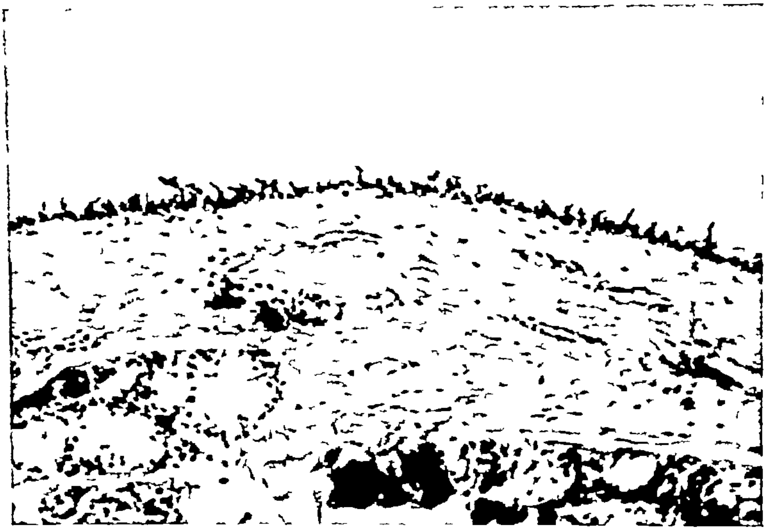

Fig 3 Trachea caudad to reversed graft in a dog 500 days after reversal of cervical trachea and nine days after permanent tracheostomy cephalad to the graft Note the absence of ciliated columnar cells which have presumably sloughed as the result of inflammation from retained secretions

A fifth dog is living as a pet, with a cervical trachea reversed more than two and one-half years ago

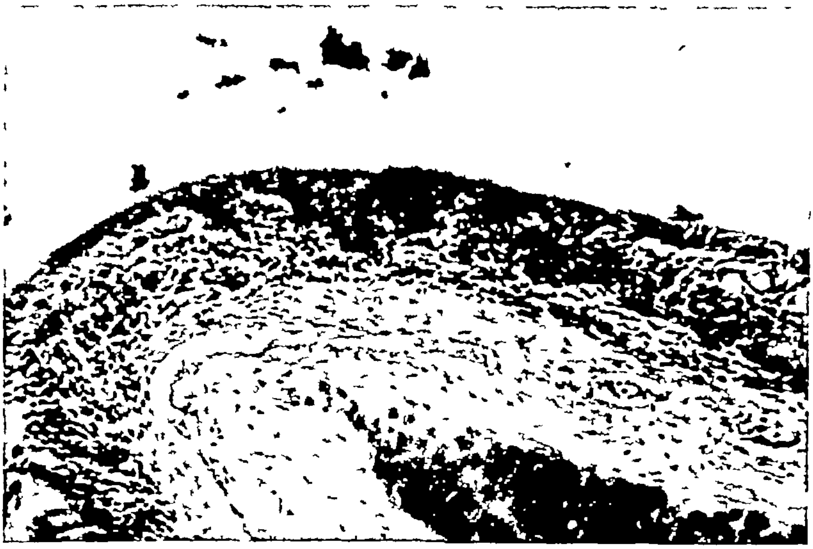

Fig 1. Squamous metaplasia of proximal anastomosis of reversed autogenous tracheal graft

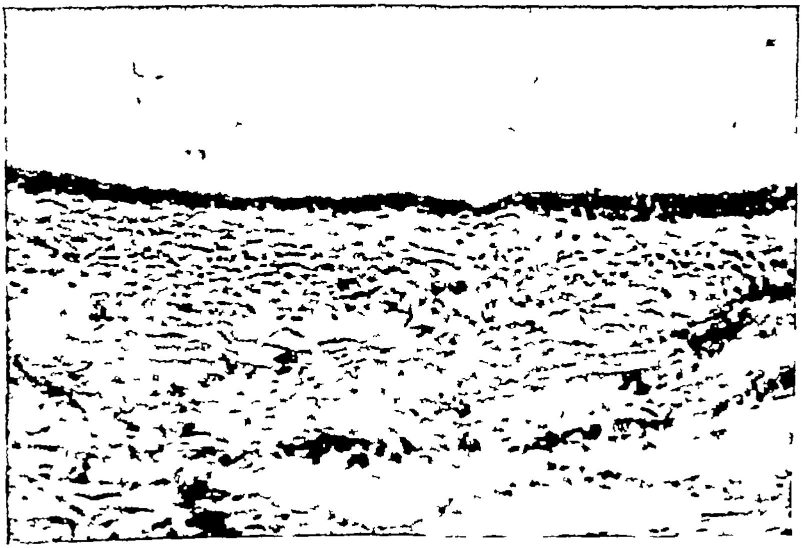

Fig 2 Persistent squamous metaplasia of proximal anastomosis 400 days after reversal of cervical trachea in the dog

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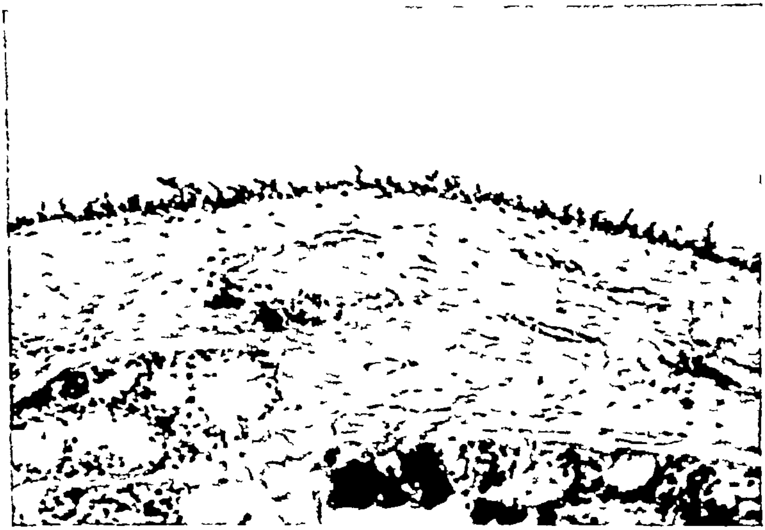

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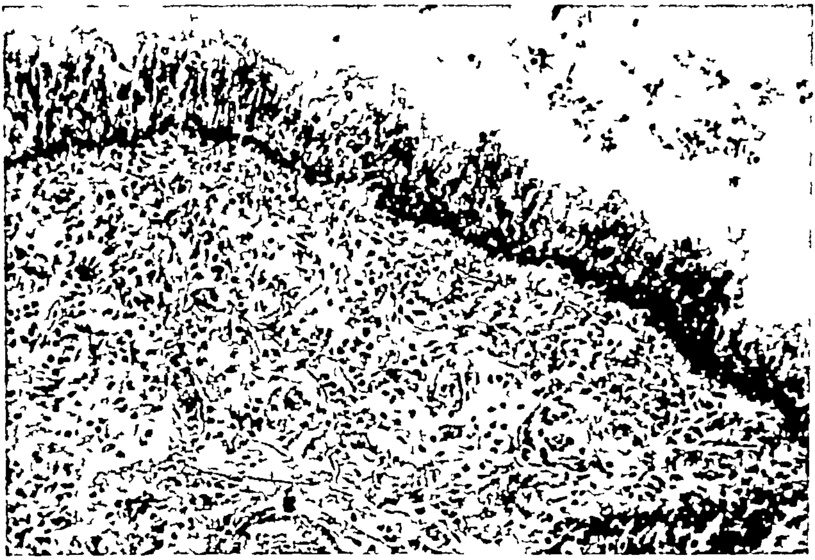

Fig 4 The reversed graft of the same animal depicted in Fig 3 Note the marked vascularity and inflammatory cells beneath the mucosa

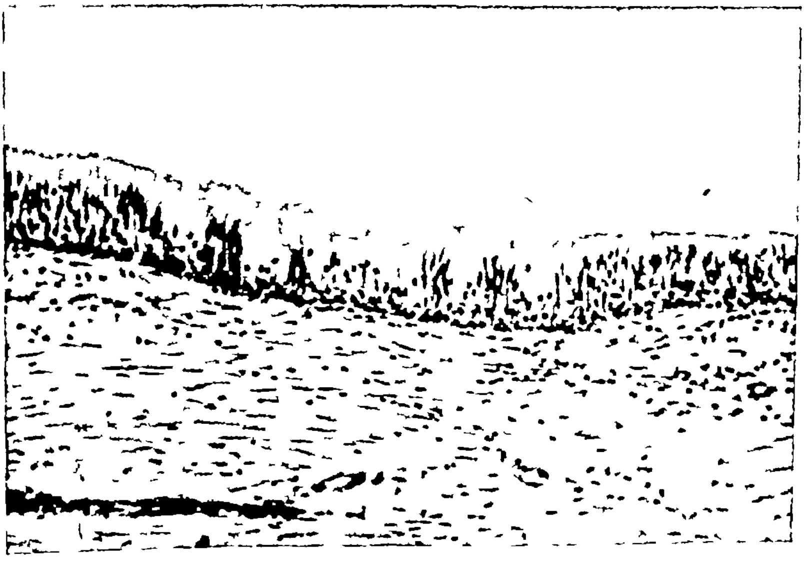

Fig 5 A tracheal graft in the dog four months following reversal showing a large number of mucus producing cells in the regenerated epithelium

## RESULTS

The two dogs killed 400 days following reversal of their cervical tracheas showed heavily ciliated columnar epithelium lining the graft There was squamous metaplasia of the proximal anastomosis which differed in no respect from the metaplastic changes found in the proximal anastomoses of all the previous specimens examined (see Figs 1, 2)

The two dogs given permanent tracheostomies died eight and nine days later of retained secretions, with asphyxia and severe tracheo-bronchitis The epithelium of their tracheas differed from that of their grafts, in that the trachea showed uniform survival of the reserve cells only, in an orderly solid sheet (see Fig 3), while the grafts showed more sub-mucosal vascularity and a thicker, more metaplastic and basophilic epithelium (see Fig 4)

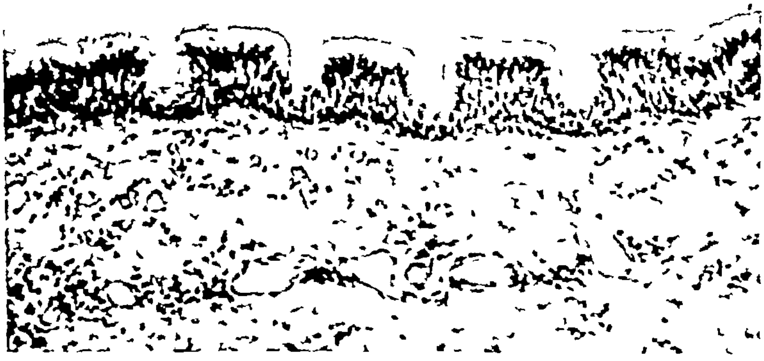

Fig 6 Another section from the same graft as Fig 5 showing mucus pits

## DISCUSSION

Whether this heavier, better preserved epithelium is the result of a better blood supply or a distorted growth pattern brought about by the previous phase of regeneration of the graft is not known

It does appear that the epithelium of the graft usually differs in some respects from the normal respiratory epithelium There are more mucus producing cells in the epithelium of the grafts (see Fig 5), and many of these cells are clumped together, forming a cluster of ciliated goblet cells located around a depression in the surface of the mucosa (see Fig 6) These glandular, mucus producing pits, lined by cilia, are more numerous than the well-known racemose glands of the tracheo-bronchial tree The "mucus pits" are also more shallow, the entire glandular aggregate being superficial to the basal layer of reserve cells of the epithelium

Even the surface of normal tracheal epithelium is pockmarked by glandular orifices when examined under suitable magnification and illumination Whether these craters represent "mucus pit" glands or openings of the racemose glands ducts is not known

## SUMMARY AND CONCLUSIONS

*1* Squamous metaplasia of the cephalad anastomosis of reversed autologous tracheal grafts persists for more than one year

*2* The mucosal lining of the grafts seems unusually well supplied with ciliated goblet cells, frequently clustered around "mucus pits"

*3* The regenerated epithelium of the grafts exhibits an abnormal response to infection, the significance of which is unknown

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# UNUSUAL TUMORS OF THE TONSIL AREA *†

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## INTRODUCTION

Since disturbances of the tonsil and its surrounding structures are commonly caused by infection, it was thought that by way of contrast a discussion of five tumors in this area would be of general interest and value

These tumors are *1* Osteoma of the inner surface of the mandible presenting in the left tonsil fossa, *2* Fibro-liposarcoma arising on the dorsum of the tongue and extending into the right tonsil fossa, *3* Mixed tumor of aberrant salivary gland in the nasopharynx invading the left posterior pillar, *4* Malignant lymphoma of the right tonsil, *5* Squamous cell carcinoma of the left tonsil The first three tumors occur rather commonly in many parts of the body but are unusual in the sites to be described, while the last two neoplasms are occasionally seen only in the tonsils

## OSTEOMA OF MANDIBLE

*Case 1* Mrs V H white, age 50 was referred on Nov 29, 1954 because of an asymptomatic medial protrusion of the left tonsil which had been found during a routine physical examination The tonsils were atrophic and the one on the left appeared to be displaced medially by a large firm, discrete, and fixed mass about 5 or 6 cm in diameter coming up from the base of the tonsil fossa The ear, nose, throat nasopharynx, larynx, sinuses, and neck showed no essential pathology, and the general examination was not contributary The report of a small biopsy was "chronic tonsillitis with focal ulceration"

Under general anesthesia on Dec 13, 1954, a vertical incision made behind the anterior pillar immediately disclosed a smooth and spherical osteoma with the atrophic tonsil stretched over it Both tonsils were *removed by dissection and snare The bony tumor was found to be attached* to the inner surface of the angle of the mandible by a very broad base By means of mastoid gouges several large fragments of the mass were removed The bone was so hard that the edge of one gouge was broken By this time it was evident that complete removal of this benign tumor would be a major procedure which was not justified by the symptoms Accordingly the wound was closed by suturing the anterior and posterior pillars together

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The pathology report by Dr Warren C Hunter was as follows In addition to tonsils there are a number of pieces of bone the largest measuring 2 5x1 5 cm having roughened and somewhat cancellous surface opposite to a smooth and convex aspect The mass cut with great difficulty and mostly appeared solid rather than cancellous

In microsections the mass proved to be extremely dense bone poor in bone cells and with a good many Haversian canals present. If this is other than an exostosis it can be termed an osteoma (see Fig 1)

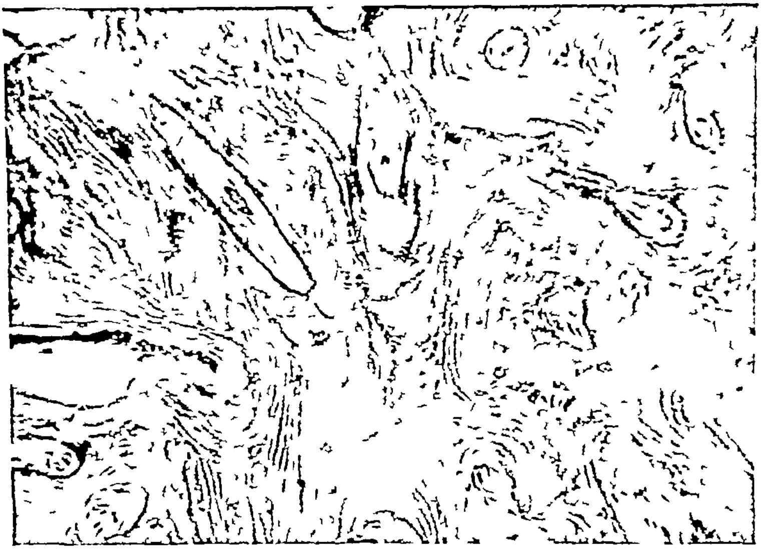

Fig 1 Case 1 Photomicrograph (X160) depicting representative structure of osteoma together with Haversian canals

By Dec 20 the edges of the wound had separated and the bare osteoma was widely exposed On Jan 21 1955 the bony mass was still completely exposed with no evidence of progress in covering by soft tissue however shortly thereafter a large superficial sequestrum was removed which revealed healthy granulations extending over the entire osteoma In a few days the area was completely covered by normal mucosa

The post-operative X ray report of Dr Arthur L Hunter on Dec 23 1954 stated Radiography of the left mandible shows a huge semi-oval calcium density projecting medial to the angle of the mandible on the left side This density measures about 5 or 6 cm in greatest diameter and has the radiographic characteristics of a huge osteoma (see Fig 2)

The patient was last seen on Aug 20 1957 at which time the mass appeared to be unchanged in size and the patient was having no throat symptoms

Thoma[1] described the removal of a similar tumor by an extraoral approach The mass was so large that it interfered with talking and prevented the wearing of an upper denture Because the osteoma was so hard it was necessary to remove part of the cortex of the mandible with the specimen The same writer states,[2] "The development (of an osteoma) may occur in any part of the maxilla and mandible and arises from preformed bone, periosteum or retained cartilage cells from the embryonic chondroskeleton Growth is progressive, but slow, and the tumor is benign in character It starts spontaneously and is believed by many to be of traumatic but noninflammatory origin Its growth generally ceases with the termination of general skeletal development"

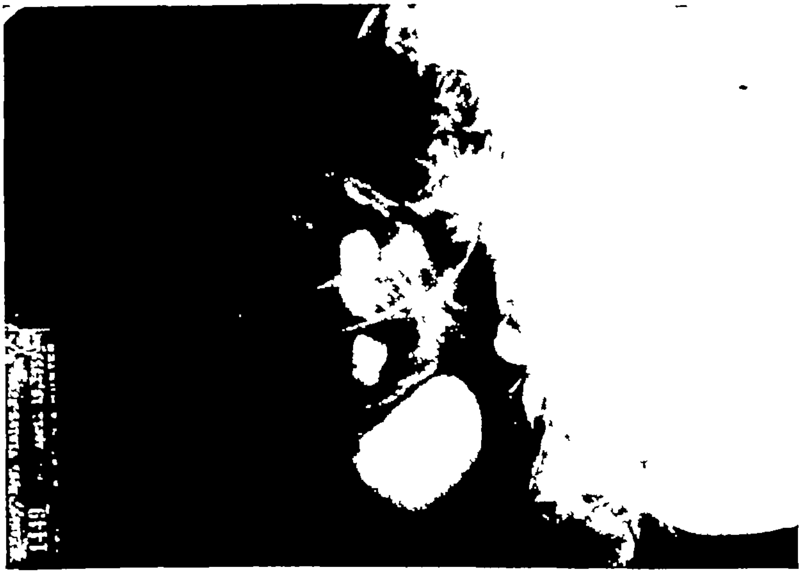

Fig 2 Case 1 Osteoma of Mandible as seen by X-ray

Uhler[3] presented the case of a man with such a large pedunculated osteoma attached to the lower first molar area that the tongue was displaced, making the intake of food difficult The tumor was thought to be the result of a blow to the lower jaw 37 years before Removal was accomplished with a Gigli saw

Rosedale and Hargraves[4] reported the case of a colored man with an osteoma of the inner surface of the mandible extending from the left lateral incisor tooth as far posteriorly as the posterior pillar of the tonsil and extending vertically from the superior surface of the mandible to the inferior surface Because of difficulty in swallowing and speaking it was removed intraorally

True osteomas occur rather frequently in the frontal sinus Ewing[5] states that these arise from fragments of cartilage connected with the ethmoid Osseous change of the maxilla and mandible often is associated with dental pathology and the occurrence of an exostosis is rather common At times, bone is combined with cartilaginous, fibrous, or other types of tissue in a neoplasm The torus palatinus and torus mandibularis are common and usually cause difficulty only in the wearing of dentures

## FIBRO-LIPOSARCOMA OF THE TONGUE

*Case 2* Mr M R white, age 45 sought treatment on Nov 4 1944 because of the sensation of a foreign body in his throat. He stated that in 1923 (age 24 yrs ) a tumor had been removed from the posterior part of his tongue The record of this procedure was not available Later he was treated by the late Dr Frank B Kistner of Portland Ore whose record was as follows This patient was seen in 1927 (age 28 yrs ) at which time a large mass was found attached to the lower outer border of the anterior surface of the right side of the epiglottis On Jan 7 this was removed by sharp dissection under suspension laryngoscopy The pathological diagnosis was adenomyxoma with doubtful malignancy In May 1941 a biopsy was taken which showed no malignancy

The examination in 1944 (age 45 yrs ) showed a rather large yellow smooth soft and lobulated mass on the right side of the tongue extending from the epiglottis to the deep surface of the right tonsil (see Fig. 3) Nothing else of significance was found in the local or general physical examination On Dec 7 1944 under general anesthesia the tumor was removed by sharp dissection along with both tonsils The tumor had extended between the capsule of the right tonsil and the fossa bed Bleeding was slight and the mass whose dimensions were 4 5x3 5x1 cm was surrounded by a definite capsule and was on the surface of the tongue The pathological diagnosis by Dr Warren C Hunter was submucous lipoma He commented that this was the first time that he had seen a lipoma in this location

The wound healed well and periodic examinations showed no recurrence until June 20 1952 (age 53 yrs ) when a discrete mass about 1 cm in diameter with a broad base was found on the right side of the tongue in the vallecular fossa The patient returned for surgery on Feb 7 1953 The tumor was now about the size of an olive and was removed by sharp dissection under local anesthesia A small adjoining mass was also resected

Thoma[1] described the removal of a similar tumor by an extraoral approach The mass was so large that it interfered with talking and prevented the wearing of an upper denture Because the osteoma was so hard it was necessary to remove part of the cortex of the mandible with the specimen The same writer states,[2] "The development (of an osteoma) may occur in any part of the maxilla and mandible and arises from preformed bone, periosteum or retained cartilage cells from the embryonic chondroskeleton Growth is progressive, but slow, and the tumor is benign in character It starts spontaneously and is believed by many to be of traumatic but noninflammatory origin Its growth generally ceases with the termination of general skeletal development "

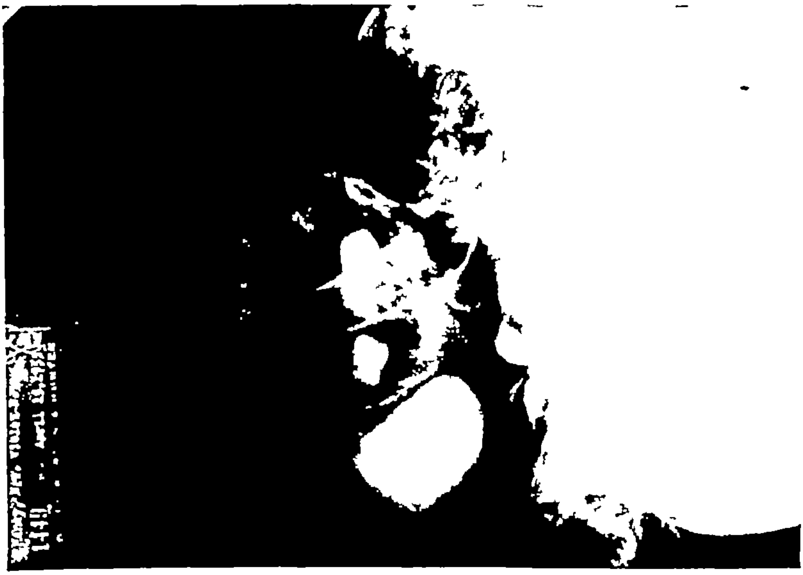

Fig 2 Case 1 Osteoma of Mandible as seen by X-ray

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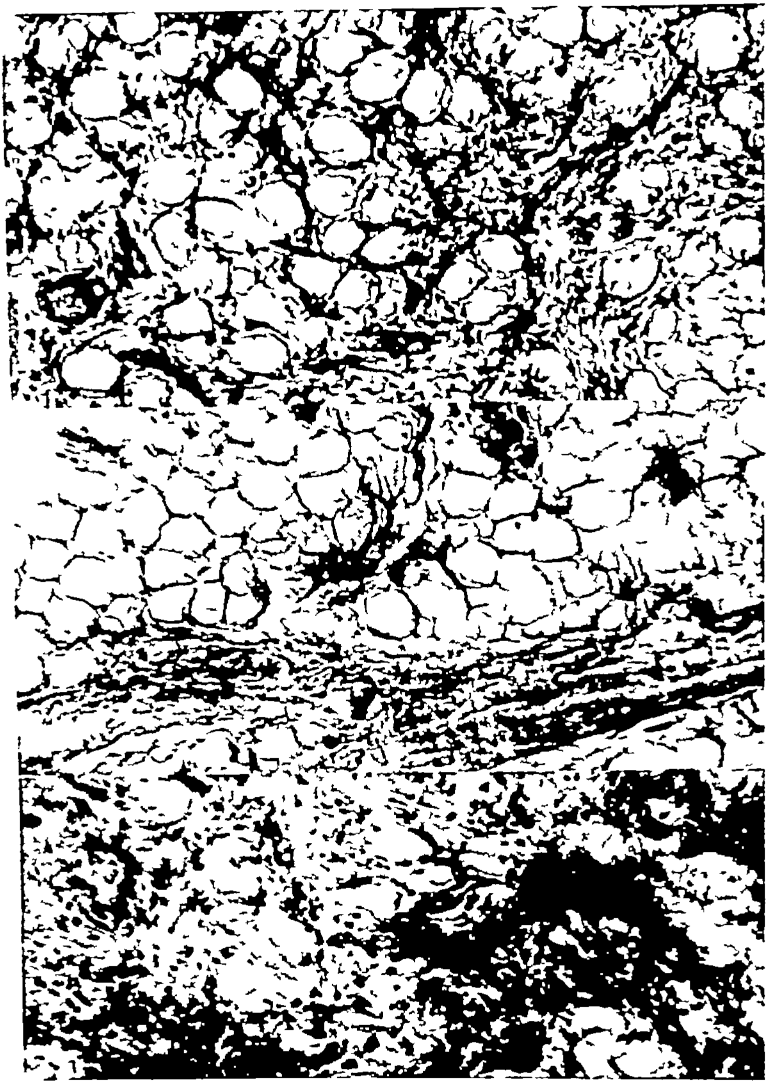

Fig 4 Case 2 Top—Photomicrograph (X160) of a representative portion of the original tumor removed in 1927 Adult-type fat cells are abundant but between these in places are elongated cells with fairly large and very deeply stained nuclei representing the sarcomatous element. Middle—Recurrent tumor of 1944 at this time entirely lipomatous and nonmalignant (X160) Lower—Representative area from the 1953 recurrence now somewhat more sarcomatous than in 1927 but still containing many adult adipose cells (X160)

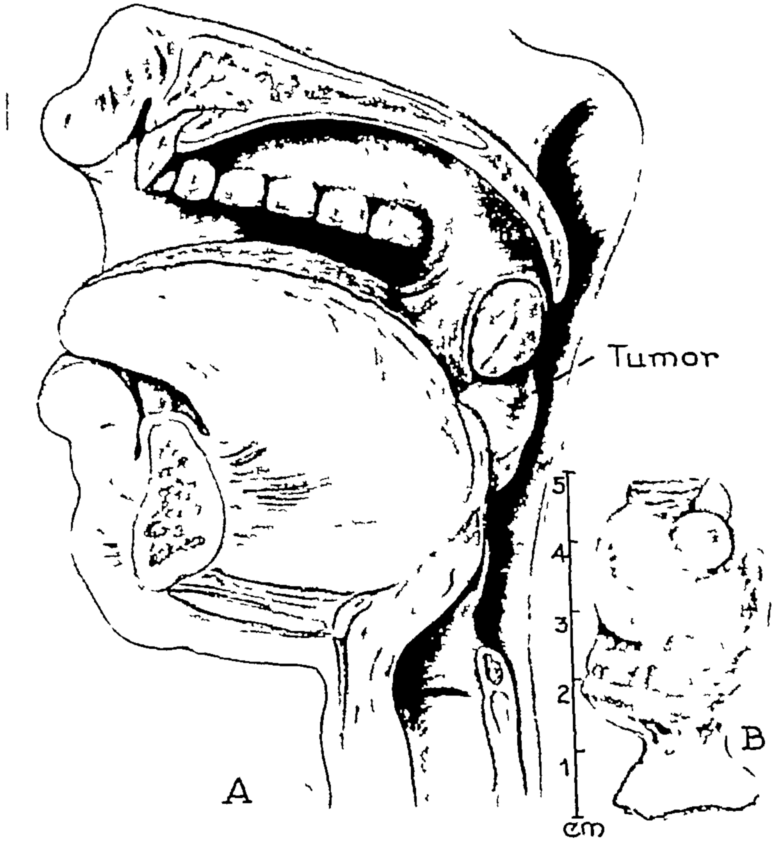

Fig 3 Case 2 Fibro-liposarcoma of dorsum of tongue extending into tonsil fossa

The pathology examination as recorded by Dr Hunter was as follows The pathological diagnosis of the tumor removed in 1927 was adenomyxoma with doubtful malignancy "

Reviewed in late 1957 the histopathology proved to be identical with that observed in the recurrence of 1953 termed recurrent fibro liposarcoma

In 1944 a mass of yellow tissue divided into two parts by a cleft surrounded by a thin fibrous zone and measuring 4 5x3 5x1 cm was reviewed

Microscopically this proved to be principally fat cells of adult type, together with some mature collagenous type connective tissue Vascularity was not at all excessive There were no lipoblastic cells The pathologic diagnosis was submucous lipoma articular, perineal and mediastinal regions They generally first appear as rounded swellings of spontaneous origin, which grow steadily or rapidly until large or bulky masses result with prominent pressure symptoms They are usually encapsulated until recurrences develop as diffusely infiltrating, highly malignant and metastasizing processes "

Boyd[10] in discussing retroperitoneal liposarcomas says "Microscopically the greater part of the mass consists of adipose tissue, but here and there may be found areas of myxomatous tissue and sarcomatous formation It appears probable that these have developed primarily and that the tumor represents an embryonal type of tissue, rather than that they are due to a transformation of the lipoma "

## MIXED TUMOR OF THE NASOPHARYNX

*Case 3* Mrs D C M white age 52 In a general physical examination by Dr Eldon W Snow on Feb 10 1957 a swelling of the left tonsil area was noted It appeared as a fullness of the soft palate and posterior pillar which pushed the tonsil forward and medially The mass did not appear to change in size and on Oct. 27 1957 was explored by Dr Snow Upon removal of the normal tonsil the tumor immediately protruded through the posterior pillar It appeared to be of the consistency of cartilage which fragmented easily and was readily separated from the surrounding tissue A large fragment was removed for biopsy and the pathological examination by Dr Warren C Hunter revealed chondrosarcoma

X ray examination by Dr Arthur L Hunter revealed a large discrete opacity about 4 cm. in diameter protruding from the left lateral wall of the nasopharynx beyond the midline with no evidence of bone destruction X ray examination of the thorax was normal Otolaryngological examination showed the soft palate and left posterior pillar to be pushed forward by a large mass covered with normal mucosa protruding into the nasopharynx from the left side It extended almost to the midline and compressed the Eustachian orifice No other significant abnormality was found

Definitive surgery was carried out by the writer on Nov 21 1957 Under general anesthesia, the left external carotid artery was ligated below the lingual branch A tracheotomy was performed to facilitate anesthesia, and the hypopharynx was completely packed off A vertical incision was made through the left side of the soft palate beginning in the tonsil fossa and extending upwardly to the posterior edge of the hard palate Tumor tissue with a definite capsule was immediately encountered It was soon found that the tumor extended into the surrounding muscles extensively By sharp and blunt dissection the large neoplasm with a wide margin of surrounding normal muscle was removed in many pieces with a minimum of bleeding The largest fragment measured 5x4x3 cm In order to remove the tumor completely it was necessary to resect large portions of the left internal pterygoid muscle the palatine muscles and the posterior pillar The resulting cavity was bounded above by the Eustachian cartilage (not involved by tumor) and

In 1953, the specimen consisted of two tissues, one both smooth and rough surfaced, very soft white to red and measuring 1 3x1x0 5 cm, the other smooth everywhere soft, white to faintly pink and having dimensions of 3x2 5x1 5 cm The cut surfaces proved to be white to faintly yellow

Over a part of the larger tissue was a covering of stratified squamous epithelium along with underlying aggregates of lymphocytes The mass consisted of connective tissue and of fat and mingling with the latter were a good many cells of varying size and with hyperchromatic nuclei The cytoplasm lacked demonstrable vacuolization in the paraffin sections, yet their form otherwise and in a background of adipose tissue gave the impression that this growth must be considered as a recurrent fibro liposarcoma, and such was the pathological diagnosis Since all of the material had been embedded there was nothing available for fat staining (see Fig 4)

In a written consultation on this patient, Dr Simeon T Cantrell of Seattle, Wash, stated that he had never seen a similar tumor on the tongue, and that it was one of the very rare forms of mesenchymal sarcoma which has considerable radio-sensitivity He suggested that this patient should not be radiated unless the tumor should recur

At the present time there is no evidence of local recurrence or metastasis Obviously this tumor had a low degree of malignancy, as shown by its long duration and its recurrence at one time as a lipoma

A patient with a simple lipoma on the anterior surface of the tongue has been reported by Braunstein[6]

Saunders[7] in reporting a lipofibroma of the larynx presents an extensive bibliography on the subject of lipoma of the larynx Several of the cited cases of primary laryngeal lipoma showed extensions of the tumor to the epiglottis and valleculae One tumor originated on the left aryepiglottic fold and was diagnosed as myxolipoma with sarcomatous changes All of these tumors were removed surgically

Knowles and Hugill[8] have reported the case of a 12-year-old child who had a primary liposarcoma in the submucosa of the naso-pharynx The patient died with metastasis to the lungs, liver and brain

Lipomas are commonly seen in many parts of the body and are usually of no major consequence Ewing[9] states that "Liposarcomas are most frequent in the intermuscular, peri-

Boyd[11] states that a mixed tumor has two components, the first of which is the epithelial cell and the second, the spindle or stellate cell, separated by abundant intercellular mucoid material He states that in places this material may closely resemble or be identical in appearance with cartilage It was considered very fortunate that this tumor was of the mixed type rather than a chondrosarcoma Wirth and Shimkin[12] report a chondrosarcoma of the nasopharynx, which was very extensive and had a fatal outcome in spite of extensive surgical removal

Mixed tumors commonly arise in the major salivary glands, and also occasionally in aberrant salivary glands widely scattered over the whole of the oral mucosa If the tumor is completely removed by the first operation, the prognosis is generally considered to be quite favorable, however, "recurrence" may follow incomplete removal In order to be sure of total removal the tissue surrounding the capsule must be resected Malignant changes are uncommon The author observed in 1946 the removal by Dr Louis Clerf of a large mixed tumor of the nasopharynx by a transpalatine approach In reporting 33 malignant tumors of the nasopharynx, Hara[13] includes two mixed salivary gland tumors

In the presently reported case, there was no connection between the nasopharyngeal tumor and the deep lobe of the parotid gland, however, Morfit[14] reported 12 mixed tumors arising from the deep lobe of the parotid and presenting in the lateral pharyngeal wall as a large mass covered with normal mucosa Occasionally also the tumor presented below the horizontal ramus of the mandible The pharyngeal prominence is to be distinguished from an aneurysm or a large carotid body tumor External removal of the large parotid mass was recommended

Sonnenschein[15] has described two mixed tumors in the soft palate These were surgically removed and are rare in this location

## MALIGNANT LYMPHOMA OF THE TONSIL

*Case 4* Mrs K L white age 60 consulted her family physician on July 3 1957 because of a sore throat of two weeks duration His exam the base of the skull, laterally by the styloid process and carotid sheath, posteriorly by the longus capitis muscle, and anteriorly by the remains of the soft palate

The postoperative course was uneventful except for trismus which has gradually improved

The pathological report by Dr Hunter of the original biopsy was The portions of tissue first seen had the color, consistency and cutting qualities of hyalin cartilage Sections contained nothing other than apparent cartilage and because of the atypical character of the nuclei the initial diagnosis was chondrosarcoma

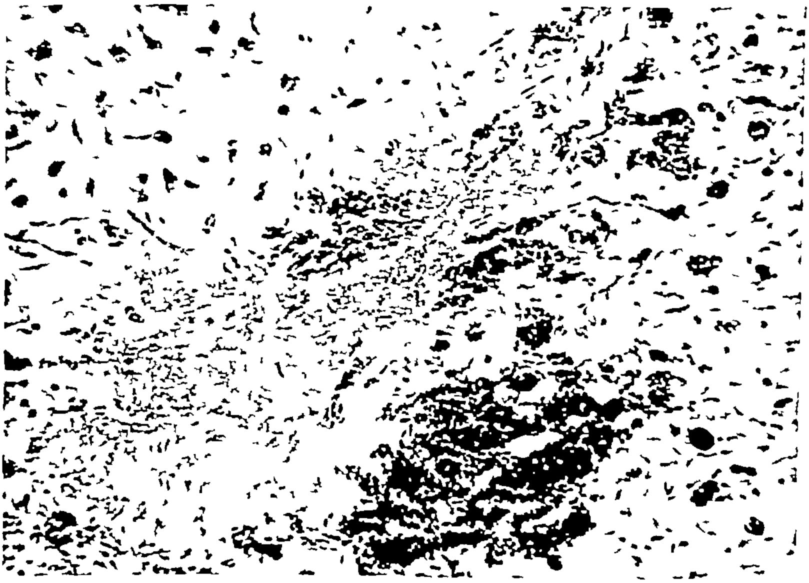

Fig 5 Case 3 Mixed salivary gland tumor (X160) this field contains many nests of epithelial cells relatively little matrix and no cartilage whereas the biopsy consisted entirely of atypical cartilage

The largest of the masses, removed on Nov 21 1957, appeared to be a partially encapsulated lobulated white tissue measuring 5x4x3 cm, cut with the consistency of cartilage and was white to yellow

Microscopically the growth consisted in large part of bluish pink to violet staining material rather poor in cells of apparent epithelial nature occurring in solid strands, and as small alveoli These had some resemblance to the alveolar epithelium of a serous type of salivary gland Mucus was not a component of the cells or the lumens of the alveoli None of the cells appeared to be of squamous type Embedded in surrounding connective tissue in close association with skeletal muscle and entirely away from the tumor were some lobules of a salivary gland of mucous type, unassociated with neoplasm

In view of the structure of the whole tumor as contrasted with the fragments making up the earlier biopsy the original diagnosis of chondrosarcoma was changed to mixed tumor of aberrant salivary gland" (see Fig 5) showed the soft palate and right pillars to be grossly normal with a gray membrane lining a normal appearing fossa In the right side of the neck, anterior to the sterno-cleidomastoid muscle was a freely movable smooth mass of rubbery consistency measuring about 10 cm in greatest diameter The remainder of the examination including an X-ray of the chest was negative X ray therapy was administered in divided doses to the throat and neck. The tumor responded well and examination on Oct. 3 1957 showed the tonsil fossa to be well healed and the mass in the neck to have completely disappeared

Malignant lymphomas of the throat and cervical lymph glands are rather common, and are usually considered to be best treated by irradiation

## CARCINOMA OF THE TONSIL

*Case 5* Mr M. O white, age 57 sought consultation because of a mass in his neck He stated that for several months he had visited various physicians in a large clinic because of a sore throat. He was told that he had an infection and was given various antibiotics which gave no relief Eventually the left side of his neck began to swell and an incision into this mass showed squamous cell carcinoma

Examination by the writer showed that a fungating tumor about 5 cm. in diameter occupied the left tonsil fossa. The soft palate and pillars were indurated and fixed and moderate trismus was present. The entire left side of the neck was greatly swollen and indurated The patient appeared to be in good general health otherwise

At that time he had already begun a course of cobalt radiotherapy under a competent physician For that reason, he was advised to continue the treatment, and that if the lesion in the tonsil was controlled radical surgery of the neck should be considered His further progress is not known.

Obviously, the prognosis in a patient such as this is discouraging

Early and small carcinomas of the tonsil can sometimes be completely removed by tonsillectomy If the tumor is more advanced, irradiation therapy is usually employed If the metastasis in the cervical lymph glands is not too far advanced, radical neck dissection is usually the best treatment if the primary lesion can be controlled

## SUMMARY

The records of five patients having tumors in a tonsil or in the surrounding structures are presented The diagnostic and treatment problems are discussed and the literature is reviewed

ination revealed the right tonsil to be enlarged and displaced medially An enlarged anterior cervical lymph gland was present on the same side Because it was thought to be a peritonsillar abscess, an incision was made above the tonsil, but no pus was found Under antibiotic therapy, the tonsil decreased somewhat in size On Aug 13, 1957, the tonsil was removed and found to be extremely large

The pathological report by Dr Jeff Minckler was as follows The tonsillar tissue is submitted in three pieces ranging from 2 5 to 3 5 cm in their greatest dimensions The epithelial surface is identified on the larger specimen The surfaces are moderately fragmented and on sectioning much destruction of the tonsillar tissue is identified The entire tissue is mottled pale pink to red Nothing suggestive of a neoplasm is encountered

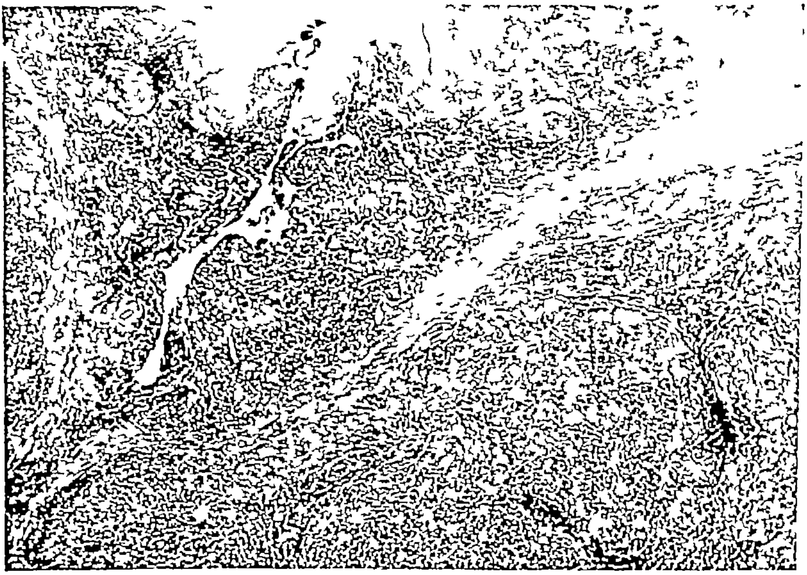

Fig 6 Case 4 At a 40X magnification the contrast between normal tonsil just below the epithelium of the crypt and the malignant lymphoma occupying the lower part of the field is quite evident

Microscopically the architectural pattern of the tonsil is altered by what is interpreted as a neoplastic process of the lymphoma group The predominant pattern is that of large follicle-like structures without distinct germinal centers composed of relatively uniform medium sized cells that have somewhat ill defined cytoplasmic outlines with suggestive tailed processes attached There is slight to moderate mitotic activity in these fields In selected areas there is somewhat more dense cellularity with somewhat larger darker staining cells and more apparent mitotic change There appears to be local infiltration of the capsular surfaces

Diagnosis Malignant lymphoma (lymphosarcoma) of the right tonsil (see Fig 6)

The otolaryngological examination by the writer on Aug 16 1957

# SINUS SYMPTOMS ORIGINATING FROM MODERN FLIGHT *

LT COL STANLEY H BEAR,
U S A F (M C)†‡

With the advent of a new era in aviation, man is ever attaining higher altitudes and traveling at faster speeds In so doing, he is encountering physical problems which interfere with his best performance and well-being One of the vital problems is the involvement of the sinuses due to barotrauma, a condition more commonly known as aerosinusitis

Aerosinusitis is an acute or chronic inflammation of one or more of the nasal accessory sinuses produced by a barometric pressure difference between the air or gas inside the sinuses and that of the surrounding atmosphere It is commonly characterized by congestion and inflammation of the lining structures Mucosal or submucosal hemorrhage may occur [1]

There are two general types of aerosinusitis which may develop the non-obstructive, which is due to the collection of mucous secretions in the ostei, or the obstructive type, which has three degrees depending upon the severity Most chronic cases will fall into the latter group and are usually of the third degree

During the past two years, I have examined, in our clinic, 48 cases of aerosinusitis of the chronic obstructive type An evaluation has been made of the incidence, predisposing factors producing the physiological disturbances, signs and symptoms, pathology, X-ray findings, treatment and sequelae

The incidence of aerosinusitis is difficult to evaluate in

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*Read at the meeting of the Middle Section American Laryngological Rhinological and Otological Society Chicago Ill Jan 13 1958

†From Surgical Service 3810th U S A F Hospital Maxwell Air Force Base Alabama

‡The opinions expressed are those of the author and do not necessarily represent the opinions of any department of the Department of Defense.

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624 Medical Arts Building

been properly briefed on the awareness of difficulty in flight, such as making slower descent and the use of the Valsalva maneuver, especially in cases of Eustachian tube involvement; however, the Valsalva maneuver is of little benefit in sinus obstruction and will not lessen the degree of symptoms. Several fliers with more than 1,000 hours in conventional aircraft experienced symptoms on their very first jet flight. In two instances, symptoms occurred during every descent in jet aircraft, yet they never experienced any difficulty in flying slower conventional aircraft.

There are two main factors which tend to produce difficulty in flight. These are a rapid change in barometric pressure, plus a predisposing factor which interferes with the air or gaseous change between the environment or nasal cavity and that of the sinus cavity. The pressure change at the various altitudes is noted on the following table.[5]

TABLE I

Altitude Based on United States Standard Atmosphere
(From Armstrong)

| Altitude (Feet) | Pressure (mm. Hg.) |
|---|---|
| 0 | 760 |
| 5,000 | 632.30 |
| 10,000 | 522.60 |
| 20,000 | 349.10 |
| 30,000 | 225.60 |
| 40,000 | 140.70 |
| 50,000 | 87.30 |

In general, on ascent from sea level to 5,000 feet, there is a decrease in barometric pressure from 760 mm. Hg. to 632.30 mm. Hg., one-sixth atmosphere, and on ascent to 18,000 feet there is a decrease to 360 mm. Hg., or one-half atmosphere. The change is reversed on descent; therefore, it is especially noted that the greater differrential pressure change is noted at the lower altitudes. This effect is more pronounced as the speed or rate of change is increased and greatly altered if a predisposing factor in any way interferes with this change. Proetz[6] states that a reduction of one-fifth atmosphere (152 mm. Hg.) pressure is ordinarily well tolerated by the mucosa, any group of cases. We were unable to correlate the incidence, because the cases were referred for final disposition after failing to respond to primary treatment. The exact number of acute cases, before becoming chronic, was undetermined. Campbell[2] reported on 35,000 simulated flights in the altitude chamber, where a direct control of all cases was able to be made, and found an incidence of 1.9 per cent. McGibbon[3] noted 18 cases in 1000 chamber flights, or incidence of 1.8 per cent.

One large airline during a one-year period, noted a major discomfort in its passengers from all causes due to air travel, averaged about eight or nine per 1,000.[4] The incidence of sinus and ear distress reported varied from 0.5 to eight per 1,000 passengers carried, and it was felt that this rate would have been higher if all passengers who experienced sinus or ear distress had reported it. Unfortunately, the number of flights made in pressurized aircraft was not differentiated from those in unpressurized aircraft.

To our knowledge, there has been no report made on the incidence of aerosinusitis resulting from jet aircraft flight. Of the 48 individuals we examined, 38 experienced symptoms of aerosinusitis in pressurized jet aircraft. Of the remaining ten cases, six occurred in pressurized conventional aircraft for a total of 44 cases in pressurized aircraft. There were four cases occurring in unpressurized conventional aircraft.

What are the factors producing this change? It was interesting to note that of the 48 aircrew members, there was no direct correlation with the flying time. The minimum number of hours flown by any of the pilots was approximately 50, and the maximum number of hours was over 5,000, when the symptoms became incapacitating. There were four cases occurring in the 0-500 hour group, eight cases in the 500-1,000 hour group, 13 cases in the 1,000-1,500 hour group, 16 cases in the 1,500-3,000 hour group, and seven cases occurring in personnel with more than 3,000 hours of flying time.

The four cases which developed in the 0-500 hour group all occurred during the flight training period in unpressurized conventional aircraft. In all instances the individuals had between 12,000 feet and ground level Some occurred at an altitude of less than 5,000 feet The condition seemed to be aggravated by the rate and duration of the pressure change

There are many predisposing factors which, in combination with a rapid barometric pressure change, either on ascent or descent, will produce an acute obstruction to the sinus passage with resulting aerosinusitis The more common, in decreasing order of occurrence, are

TABLE II

Predisposing Factors in Etiology of Aerosinusitis

| | |
|---|---|
| Deflection of Nasal Septum (More than 50%) | 23 |
| Hypertrophy of middle turbinate with encroachment of middle meatus and nasofrontal duct orifice | 14 |
| Nasal allergy | 10 |
| Upper respiratory infection | 7 |
| Polyps in middle meatus | 7 |
| Mucocele | 2 |
| Septal spur | 1 |
| Hypertrophic rhinitis | 1 |
| No abnormal finding at examination | 1 |
| Cyst on floor of maxillary sinus | 1 |
| Vasomotor rhinitis | 1 |
| Osteoma over sinus orifice of nasofrontal duct | 1 |

In some cases it was noted that more than one factor was prevalent, such as allergy and nasal polyps, or deflection of the nasal septum with encroachment of the middle turbinate on the nasofrontal duct, thus, the total on the above chart will, in some instances, have more than one etiologic factor It is important to note that deflection of the septum was high in over two-thirds of the cases This resulted in the impingement of the middle turbinates laterally over the opening of the nasofrontal duct with encroachment on the duct orifice This was a significant finding in nearly 50 per cent of the cases The one case of osteoma was located at the orifice of the superior part of the nasofrontal duct and caused almost complete collapse of the mucosa lining the duct This acted as a suction valve on descent and would obstruct the orifice, producing severe symptoms Nasal allergy and polyps were present in seven of the cases They were obstructing the middle meatus in all instances The case of vasomotor rhinitis but when in much excess of this may be expected to be followed by hemorrhage, either mucosal or submucosal Behnke[7] found that if a sinus opening is obstructed and an increased pressure of one to two pounds transmitted to the body tissues and circulating blood, an area of relatively decreased pressure is produced in the air spaces This results in a cupping action in the cavity and a vascular congestion of the mucous membrane Tension is produced on the cells of the living membrane, and the blood vessels distributed in tissue surrounding the occluded space Pain is present in and around the involved area, associated with congestion and hemorrhage

Today most modern pressurized aircraft fly at a cabin altitude of approximately 8,000, and those of future jet operations will be at or near this altitude on long flights There is only a slight difference on ascent or descent of selected cabin altitude from that of the plane, therefore, from 8,000 feet to ground level, pressurization will have little beneficial effect on the individual crew member or passenger At the present time C A A Regulations allow a maximum rate of change of cabin altitude equivalent to approximately 300 feet per minute[8] This applies to both ascent and descent In future jet aircraft operations there are times when a faster rate of descent may be produced through loss of pressurization, faulty pressurization valves, instrument approaches, or in cases of fuel starvation Any one of these factors will necessitate a more rapid rate of barometric pressure change, and added to a predisposing intrinsic factor in the passenger or crew member, sinus symptoms will likely result

It is worthy to note at this point that there is a difference in the pressurization between military jet aircraft and those of anticipated commercial design At lower levels, the altitude of pressurization is approximately 12,000 to 13,000, rather than 8,000 feet, and the differential pressure at high altitudes is usually the maximum of 5-plus pounds per square inch, while the commercial planes are designed for 8-plus pounds per square inch for operation

In all the cases in our series, there were only a few occurring above 15,000 feet cabin altitude The majority occurred sinus and four with both frontal and maxillary sinuses involved. The fourth major symptom was that of a feeling of pressure over the involved sinus, and occurred in seven cases. The fifth predominant symptom or sign was evidence of a delayed bleeding, usually of old blood, occurring 24 or more hours after primary involvement. This was noted on expectoration upon arising in the morning, or on blowing the nose, when blood-streaked mucous would be present. The lesser symptoms are noted on the Table above.

This discussion does not include the ethmoids and sphenoid sinuses, because no case of aerosinusitis occurred where only the ethmoid and sphenoid was primarily involved. When there is severe involvement of either maxillary or frontal sinuses there may be associated involvement of the ethmoid sinus, but it is not felt to be the cause of the primary symptom complex. This was also the finding of other authors.[2,3] As previously noted, the frontal sinus was most frequently involved, next, the frontal and maxillary, with the maxillary sinus the least involved. Campbell and McGibbon[2,3] also found the frontal sinus to be the most frequently involved, while Wright, in his series, found the most frequent site of involvement to be the maxillary.[9] The reasoning for greater involvement of the frontal sinus is based on the greater length of the nasofrontal duct and its tortuous path and small caliber

TABLE III

Subjective Symptoms Experienced with Reference to Involved Sinus

| | Frontal | Maxillary | Frontal and Maxillary |
|---|---|---|---|
| Sharp pain from descent | 23 | 7 | 2 |
| Sharp pain from ascent | 0 | 1 | 0 |
| Pain from ascent and descent | 3 | 0 | 4 |
| Generalized headache | 2 | 0 | 3 |
| Pressure over sinus | 3 | 2 | 2 |
| Nasal obstruction | 4 | 3 | 2 |
| Bleeding (delayed) | 4 | 0 | 2 |
| Blurring of vision | 3 | 0 | 0 |
| Lacrimation | 2 | 0 | 0 |
| Swelling of upper eyelid | 1 | 0 | 0 |
| Rhinorrhea | 0 | 1 | 1 |
| Plugged ears | 3 | 0 | 1 |

was in a cadet in training period, and was aggravated by an emotional problem On flying, his nose would completely obstruct, causing pain in sinus He was recommended for psychiatric evaluation and elimination from flying duties

The above conditions were present even in a select group of individuals Aircrew members were given rigid acceptance physical examinations, however, in most instances the deformities were acquired or developed during their career In addition, most pilots had been indoctrinated in the preventive medical aspects of flying and proper care of themselves during flight The average air passenger is not as well indoctrinated in active and preventive measures that can be performed while flying Many prospective passengers may have a nasal allergy of sufficient degree to be symptomatic on descent, active sinus pathology, upper respiratory infection, nasal obstruction of one sort or another, or a marked degree of apprehension and anxiety All of these act as predisposing factors, and when subjected to a rapid change of descent will produce aerosinusitis of one degree or another On ascent, the predisposing condition is basically intra-sinus, or in the osteum or duct of the sinus, while on descent the difficulty present is in the nasal cavity or surrounding structures in the area of the duct orifices leading into the sinus, as noted in the previously mentioned causative factors From these findings one is able to deduce whether the difficulty will be encountered on ascent or descent, or both

There are many symptoms produced by aerosinusitis, but the predominant symptom in most cases is pain located over the involved sinus It is described as being sharp, lancinating in character, non-radiating and occurring most often during descent The frontal sinus was involved in 23 instances, the maxillary sinus in seven, and both frontal and maxillary in two instances (see Table III)

The second most common symptom was that of nasal obstruction This occurred in nine cases and was almost equally divided, with involvement of either the frontal or maxillary sinus There were seven cases of pain on both ascent and descent, with three associated with involvement of the frontal orifice This results in free bleeding from the mucosa surface or submucosally, producing submucosal hematoma This was noted in four of our cases Campbell was able to demonstrate the same findings in his experiment with a dog in an altitude chamber

The treatment of aerosinusitis usually falls into one of two categories the acute phase, and the chronic or persistent type The acute stage is treated conservatively with treatment initiated as soon as possible after symptoms occur Treatment consists in the use of vasocontrictor sprays and packs, steam inhalation, antibiotics prophylactically, and anodynes for control of discomfort In severe cases, applicators of 5 per cent cocaine and 1 per cent ephedrine are placed directly in the middle meatus at the opening of the nasofrontal duct of the side involved Depending on the time interval following initiation of the first symptoms, most cases will respond to conservative management It is worthy of mention that the longer the interval before treatment is begun, the more difficult it is to obtain patency of the involved sinus

TABLE IV

X ray Findings in Aerosinusitis

| | |
|---|---|
| **FRONTAL** | |
| Clouding frontal | 19 |
| Submucosal hemorrhage | 5 |
| Polypoid hyperplasia of sinus mucosa | 3 |
| Mucocele with hemorrhage | 2 |
| Osteoma at orifice of nasofrontal duct | 1 |
| Large ethmoid cell at orifice of nasofrontal duct | 1 |
| No sinuses present | 1 |
| Fluid level | 1 |
| No abnormal findings | 1 |
| **MAXILLARY** | |
| Clouding | 5 |
| Polypoid hyperplasia | 3 |
| Retention cyst floor of maxillary sinus | 2 |
| **BOTH FRONTAL AND MAXILLARY** | |
| Clouding | 8 |
| Hyperplastic scarring | 2 |
| Polypoid mucous membrane | 2 |

of opening The opening of the maxillary sinus is larger and may have accessory openings Von Diringshofer[10] states that more involvement is expected in individuals with large frontal sinuses, but in one of our cases with severe frontal pain there was only a small frontal cell and no development of the frontal sinuses

X-ray examination is an important phase in the evaluation of aerosinusitis When possible they should be taken immediately as well as several days later if symptoms and signs persist It has been noted in cases where there is either mucosal or submucosal bleeding that definite delineation of the area involved may not be demonstrated until the bleeding is organized into a hematoma One of the most difficult X-ray diagnoses to make is submucosal hemorrhage It is very helpful to have previous X-ray films to help differentiate from polypoid hypertrophy or polyps The latter is uncommon in the frontal sinus, otherwise, the clinical history must be evaluated to rule out the presence of nasal polyps and allergy This was the opinion of Coche[11], also in four of our cases of bleeding with hematoma found on X-ray The views used in routine evaluation are Caldwell, Waters, and lateral views When indicated, laminograms are beneficial in making a differential diagnosis (see Table IV)

There were two cases in which more than one finding was made The pathology of aerosinusitis varies, depending on the etiologic factor and the degree of intra-sinus or naso-frontal duct changes The histologic structure of the mucosa is a continuation of the nasal respiratory mucosa with slight variations The submucosa is thinner and tends to blend with the fibrous periosteum of the underlying bony sinus wall The epithelium is a thinner cuboidal-like, stratified ciliated structure The resulting sinus mucosa changes can vary from thickening of the mucosa either inflammatory or polypoid, or there can be presence of fluid, blood, mucous, or purulent secretions in the chamber of the sinus In some cases, mucoceles will be present while others have osteoma in the cavity covered with a very thin mucosa Probably the most marked change is that noted in rapid changes of barometric pressure with the complete occlusion of the sinus partial turbinectomy of the anterior third of the middle turbinate because of polypoid hypertrophy encroaching on the opening of the nasofrontal duct There was one case of vasomotor rhinitis which was due to an emotional disturbance, and it was recommended that the individual have psychiatric evaluation and be eliminated from flying duties

As a group, chronic cases of aerosinusitis must have treatment directed to the precipitating factor, and in most instances the condition can be corrected only by surgical or allergic management It is easy to ascertain that conservative management will be of little avail where these conditions exist Many of the predisposing factors would not require surgical intervention if the individual were not flying, however, when required to fly either as passenger or aircrew member, surgical correction is necessary to alleviate the condition

Of the 48 cases, there were three cases which were entirely unsuccessful following treatment two of these cases showed marked nasal polyposis and polypoid hypertrophy of the turbinates and an underlying allergic condition The individuals were unable to fly without repeated bouts of aerosinusitis The other case was that of the vasomotor rhinitis, for which no treatment was indicated as it was felt to be due to an emotional basis There were three cases in which the individuals were able to fly, but at intermittent intervals would still experience symptoms, usually not to the degree of incapacitation from flying duties Two of these cases were allergic rhinitis with polyposis, while the third case was that of recurrent upper respiratory infection This individual is still undergoing treatment to determine the etiology of his infection. The remaining 41 cases have been returned to flying duty and have experienced no difficulty in most cases, and minimal symptoms in a few cases which did not interfere with duty performance All cases were followed for a minimum of one year, however, due to loss of contact and follow-up in some cases the incidence of recurrence may have been slightly higher One case has recently been discharged from the hospital following frontal sinus surgery for submucosal hemorrhage and obstruction to the nasofrontal duct He has

In our series, almost all the cases were of a chronic nature, having been referred when conservative management failed, or when there was a recurrence of the condition at frequent intervals Following is a table showing the various treatments utilized in the 48 cases of our series

In several cases, more than one procedure or combined procedures were necessary to correct the condition In 20 cases, conservative management was used which consisted of antibiotics when indicated, vasoconstrictors and steam inhalation, or minor surgical manipulation to produce a patent osteum of the involved sinus The conservative treatment was mainly combined with infraction of the middle turbinate which was necessary in 13 cases, and in cases of post-polypectomy to maintain normal drainage, however, there were 19 cases in which it was necessary to perform a submucous resection (Killian type) In all but seven of these cases, the obstruction was located in the region of the middle turbinate, and in several cases following resection, infraction of the middle turbinate was combined in the treatment Four cases of frontal sinusotomy, by the Lynch approach, were necessary to remove the frontal sinus pathology and obtain a patent nasofrontal duct Allergic management was utilized in five cases with fair results In one case of an antral cyst, an antral window was performed with curettement of the cyst Two cases of recurrent purulent infection of the sinus were treated by irrigation, one was of the frontal sinus, the other, of the maxillary sinus Two cases were surgically treated by

TABLE V

Treatment of Aerosinusitis (Chronic Cases)

| | |
|---|---|
| Conservative (antibiotics, vasoconstrictors, steam inhalation) | 20 |
| Submucous resection | 19 |
| Infraction of middle turbinate | 13 |
| Polypectomy | 7 |
| Allergic management | 5 |
| Frontal sinusotomy (Lynch approach) | 4 |
| Antral window | 1 |
| Vasomotor rhinitis* | 1 |

*Vasomotor rhinitis—due to emotional disturbance Recommended elimination from flying duties

# MANAGEMENT OF SINUSITIS IN CHILDREN *

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Sinusitis, either alone or associated with some other inflammatory process in the respiratory tract or related areas, occurs frequently in childhood Although this fact has been demonstrated and reported many times in the past, it seems that in this age of antibiotics its re-emphasis is indicated

Dependence on antibiotics alone, and especially on short courses of them, during acute respiratory tract infections may only modify or mask associated acute sinusitis

Failure to examine the nose and nasopharynx completely when possible, or to obtain roentgenologic views of the paranasal sinuses, often causes failure in diagnosis Birdsall[1] stated that nasal sinus infection in children is common, but is often overlooked because of its usually insidious onset, the lack of definite symptoms, and the difficulty of examining the affected parts

From the ages of four or five most children who are co-operative can be given satisfactory nasal examination Children this old frequently will be co-operative on nasopharyngeal examinations with the small to medium-sized mirrors A brief explanation of what is about to happen, and a demonstration of quiet rhythmical breathing often will convert a skeptical child into a most co-operative youngster If the tongue depressor and nasopharyngeal mirror are introduced simultaneously, the number of satisfactory nasopharyngeal examinations will be increased This method of introducing the instruments relieves the child of the "double jeopardy" of separate instrumentations

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not been returned to flying duty, but exhibits a patent duct at the present time and will be given trial indoctrination in the altitude pressure chamber to see whether his results have been successful before returning to full flying duties

In all cases of aerosinusitis, treatment is directed to removing the etiologic factor as well as the existing condition

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several days before attempting therapy directed to the nose Antihistaminic drugs are of particular value in cases with a history of vasomotor or allergic rhinitis

Treatment directed to the nose usually is a matter of personal choice Prolonged use of vasoconstrictors often produces the familiar rebound phenomena Application of argyrol packs to the middle meatus and in the nasal chamber, followed by gentle suction, may prove of value in the removal of purulent secretion from the nose and sinuses In some children lavage of the maxillary sinus via the natural ostium can be carried out after the acute edematous stage has subsided

In an instance of acute ethmoiditis with external manifestations, as is found occasionally in a young child, surgical drainage may be necessary, however, if seen in the early stages this situation will usually respond to antibiotic treatment

Heat applied to the area over the involved sinus or sinuses may afford some relief of pain, however, sometimes it may exacerbate the pain Increasing the humidity in the patient's bedroom and making him comfortable are beneficial in his general care

During his course of treatment the patient should be reexamined for conditions which may have influenced the onset of the sinusitis or the application of therapeutic measures Enlarged adenoids, septal deflections, and allergic changes in the nasal mucosa are commonly occurring factors predisposing to acute sinusitis

The status of the patient's general health should be investigated Whatever general measures are necessary to improve it should be carried out, also it may be necessary to remove enlarged adenoids or a septal deflection to gain final resolution of the disease

Roentgen therapy has been used successfully in the treatment of acute or subacute sinusitis in the past Laing[4] reported treatment with Roentgen therapy in 900 cases of subacute sinusitis in children, 639 of whom were cured during

Obviously the anatomic development of the paranasal sinuses in accord with age has an effect on the sites in which infection may develop In older children the roentgenologic views are particularly helpful in localizing the site of infection Maresh,[2] in a study of routine roentgenograms of the sinuses of 100 children who were followed from birth to maturity, observed many variations in the size and shape of antrums, ethmoid cells, and frontal sinuses

## DIAGNOSIS AND SYMPTOMATOLOGY

Sinusitis should be included in the differential diagnosis when symptoms of prolonged rhinorrhea, coughing, frequent sniffling, or throat clearing are present A history of recurrent respiratory infections, otitis media, secretory otitis, and sore throats should suggest the possibility of the presence of sinusitis Wishart[3] stated that the most frequent complaint in an otherwise healthy child in whom sinusitis is discovered is repeated head colds

In cases of small children the history obtained from the parents and the objective findings on examination, with the findings from roentgenologic examination in some instances, usually will suffice in making the diagnoses Older children often can contribute to their history, and should be encouraged to do so Frequently such children describe their symptoms accurately, especially when pain is present in acute sinusitis or in a flare-up of chronic disease

In the history, allergy affecting either the patient or his family should not be overlooked

## MANAGEMENT OF ACUTE SINUSITIS

The best basis for management of acute sinusitis in children is consideration of the child as a whole and the severity of his infection A culture of the nasal secretions should be made and tests of sensitivity to antibiotics performed The child's reaction to obtaining the material for culture from his nose may indicate the degree of co-operativeness to be expected in carrying out local treatment If the infection is severe enough to warrant the use of antibiotics one may wait sinuses and ethmoids, particularly the left antrum. Skin tests were made which showed sensitivity to cat hair cattle hair goat hair, house dust, mixed feathers pyrethrum and giant and small ragweed

A diagnosis of allergic rhinitis and sinusitis was made The treatment consisted of giving the child an antihistaminic drug for two weeks, after which he was re-examined The nose then appeared to be normal with no evidence of any unusual discharge New roentgenograms showed marked clearing of the paranasal sinuses

*Comment* This case is an example of sinusitis superimposed on hay fever, and illustrates the improvement which occurred from the use of an antihistaminic prescription during the recession of the hay fever season Further care in regard to the allergic manifestations was advised

*Case 2* A seven year-old girl was registered at the clinic Nov 8 1957 She had had pneumonia approximately two months prior to her registration After five days in the hospital and two weeks at home for recovery she had returned to school, but after two days in school left otitis media developed To combat this ear infection she had been given antibiotics for a few days (The exact type of antibiotic and the number of days that it was given could not be determined at the clinic ) Approximately a week later the patient developed a sore throat and a course of penicillin had been administered

On Oct. 30, the child had been seen in consultation by an oto-rhino-laryngologist A diagnosis of sinusitis had been made nasal irrigations had been carried out and she had seemed to improve On Nov 6 however she complained of a sore throat again and her trip to the clinic followed

She was first examined in the Section of Pediatrics Only normal findings resulted from general examination a roentgenogram of the lungs blood counts urinalysis and electrophoresis of serum protein

The child was examined in the Section of Otolaryngology and Rhinology, and her eardrums were found to be intact although the left showed slight infection from the recent acute otitis media Her hearing of tuning forks seemed normal The nose looked clear on examination, and no pus was visible on anterior rhinoscopy The turbinates were only slightly congested Roentgenograms of the child s sinuses showed involvement, particularly of the antra and especially on the left. The tonsils had been removed and the nasopharynx contained only a minimal amount of lymphoid tissue A culture of the nasal secretion was negative

It was thought that this patient's disorder was sinusitis the diagnosis depending largely on the history and on the appearance of the roentgenograms of the sinuses A two week trial of antibiotics was prescribed and the patient was advised to return at its conclusion

She did return at that time On examination her nose appeared normal and in roentgenograms her sinuses seemed clear The child was feeling well.

*Comment* This is a case of recurring upper respiratory infection, sore throats, and otitis media, in which a diagnosis of sinusitis was made largely on the history and roentgenographic findings The response to a two-week course of an one series of treatments, however, with the knowledge of risks involved in exposure to radiation I prefer not to use it for children

## MANAGEMENT OF CHRONIC SINUSITIS IN CHILDREN

Adequate treatment may include several types of therapy, and the physician should not limit himself to an inflexible routine, rather, he should avail himself of all procedures, and use them as the situation demands, to restore the paranasal sinuses to their normal physiologic state

The treatment of chronic sinusitis follows the same principles in using antibiotics and intranasal therapy which were mentioned in the treatment of acute sinusitis Lavage of the maxillary sinus via its natural ostium can be accomplished in many older children

If surgical treatment is necessary it usually can be done intranasally, except for most instances in which external manifestations exist

The patient's general health should be evaluated A search for predisposing factors should be made, and their eradication accomplished, and again, the history of allergy in the patient or his family should not be overlooked The rather special problem of chronic sinusitis, associated with bronchiectasis, is not within the scope of this presentation, but the possibility of a co-existing bronchiectasis must be ruled out in all cases of chronic sinusitis

## REPORT OF CASES

*Case 1* An 11 year-old boy was registered at the Mayo Clinic on Sept 26 1957 His complaint was that sneezing, itching of the eyes, and nasal discharge had persisted for one month After a general examination in the Section of Pediatrics an ear, nose, and throat examination was requested

In the Section of Otolaryngology and Rhinology, examination of the ears revealed no abnormalities Examination of the nose showed much thick, sticky mucoid discharge on both sides particularly on the left some of which was yellowish and obviously mucopurulent The turbinates were moderately congested on both sides Pus was demonstrated coming from the natural ostium of the left antrum The tonsils had been removed There was a thick mucoid discharge in the nasopharynx, along with some mucopurulent material

Roentgenograms of the sinuses showed thickening about the maxillary rhinitis on the paternal side of the family The child had been taking an antibiotic of an undiscoverable type for 11 days prior to her admission for examination.

On examination of the ears the tympanic membranes were intact with very slight redness on the right The nasal septum was straight There was mucopus on both sides of the nose The tonsils were of size 2 on the basis of 1 to 4 The nasopharynx was examined with a mirror and a good view was obtained it was noted that an adenoid blocked most of the choana. On roentgenograms of the sinuses both antra were diffusely cloudy A culture of the nasal secretions was reported as showing usual flora

The patient was given penicillin for ten days At the end of that time the nose looked clear and no discharge was noted on examination of the nasopharynx Roentgenograms showed clearing of the paranasal sinuses

Arrangements were made for removal of the tonsils and adenoids this was done June 15 1956 After the operation the child got along well and was dismissed June 21, 1956

The child was observed a year later during the course of a common cold, however the cold cleared in eight days without complications or recurrence of sinusitis

*Comment* This case is an instance in which an enlarged adenoid obstructing the choana seemed to play an important part in the persistence of the patient's nasal symptoms and sinusitis

## SUMMARY AND CONCLUSIONS

The occurrence of sinusitis in childhood deserves re-emphasis A short course of antibiotics may only modify or mask an acute sinusitis during the course of an upper respiratory infection Examination of the nose and nasopharynx should be complete when at all possible The value of roentgenograms and the history obtained from the parents and the child is great

The foregoing diagnostic principles and a discussion of the management of acute and chronic sinusitis in children have been illustrated in reports of four cases

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antibiotic was excellent, and the roentgenograms which were taken at the end of this treatment illustrated marked clearing within the sinuses There was no history of allergy in the family of the patient

*Case 3* A six year old boy was registered at the clinic Nov 28, 1956 He had had persistent nasal obstruction for at least a year or so Infections of the upper part of the respiratory tract had been frequent and he had had pneumonia in 1952 There was no history of a definite allergic background but the patient's mother had had mild vasomotor rhinitis

In the general examination nothing out of the ordinary was found except mild obesity He was referred to the Section of Otolaryngology and Rhinology Our examination revealed the tympanic membranes to be intact, but they appeared slightly dull and his hearing seemed to be reduced very slightly through the entire range in both ears An audiogram showed very slight bilateral conductive deafness On nasal examination the nasal airways seemed to be open, however, mucus was pooled on the nasal floor, and when this was removed the adenoid could be seen obstructing the choana The tonsils were enlarged (grade III, on a basis of 1 to 4 with one being slightest), and combined tonsillectomy and adenoidectomy was advised The operation was carried out Nov 30 1956, and large masses of adenoid, and the tonsils were removed

The patient then got along very well until three weeks later when he developed an upper respiratory infection On examination a large amount of pus was observed in each nasal passage A culture of the discharge was reported as showing usual flora Tetracycline (achromycin) was prescribed, and the child's nose cleared nicely after a ten days' trial

The patient was again seen on January 23 1957, with a report that a cough had developed two days previously, and he had coughed most of the night prior to his examination His case was followed for several weeks, but the situation did not clear, and a culture again was made of the nasal secretions, this time showing many Hemophilus influenzae organisms Electrophoresis of serum protein gave findings within normal limits Roentgenograms of the sinuses showed cloudiness throughout all of them The patient was given a preparation of streptomycin with dihydrostreptomycin (distrycin) 500 mg twice daily for ten days and therapy directed to the nose was begun with shrinkage and suction and application of argyrol packs to the middle meatus on each side This was carried out for two weeks, after which the nose was clean the child was breathing freely and roentgenograms of the sinuses showed marked improvement, there being only a minimal amount of thickening in the left antrum Clinically the child was well

The case has been followed since and during one more upper respiratory infection the boy has gotten along well, with no further recurrences of his sinusitis

*Comment* This case illustrates the need in many instances of treatment to the nose as well as antibiotics in order to clear a sinusitis

*Case 4* A 4½ year old girl was registered at the clinic May 3 1956 A history of repeated prolonged colds worse in the Winter months was obtained She had less difficulty during the Summer and her symptoms were not related to the hay fever season There was a history of allergic nasion, the chisel may force the ends of the fractured bones into the lumen of the sinus, causing frontal sinusitis

### FRONTAL SINUS RELATIONSHIPS

At the *nasal notch* of the frontal bone, the floor of the frontal sinus is normally at the level of the glabella, but in some cases, it may extend as far down as the middle-third of the nasal bones (over-developed sinus), or it may stop short of the glabella (under-developed sinus)

### OVERDEVELOPED FRONTAL SINUS

When the frontal sinus extends beyond the glabella, its floor is attached directly to the inner surfaces of the nasal bones, which in this instance become part of the anterior wall of the sinus (see Fig 1)

Thus, manipulations of the nasal bones at the nasion may injure the frontal sinus A natural protection is given by the fact that the periosteum, which covers the posterior surface of the anterior wall of the frontal sinus, is tough and loosely attached Its toughness gives it a good deal of resistance to cutting by sharp instruments, and its looseness renders it easily detachable at the slightest pressure These two favorable conditions form a very valuable protection against accidental entry into the lumen of the sinus when an ostectomy is performed

X-ray studies will give valuable information about the size and extent of the frontal sinus and its relationship to the nasal bones

### UNDERDEVELOPED FRONTAL SINUS

When the frontal sinus is not well-developed, it will stop short of the glabella, and a block of compact bone will be found where the sinus is normally located At the nasion this block of compact bone fuses with the nasal bones, the frontal processes of the maxillae, the bony nasal septum, the frontal spine and the nasal notch of the frontal bone, to form a huge block of solid bone, which will make the ostectomy a difficult procedure

# ANATOMICAL OBSERVATIONS FOR RHINOPLASTIC SURGERY *

ROMEO A LUONGO, M D ,
and
ROMEO A LUONGO, JR , M D ,
Philadelphia, Pa

## ANATOMIC RELATIONSHIPS AT THE NASION

The squama of the frontal bone projects downwards, at the midline, to form the *nasal part* The lower margin of the nasal part, which is beveled, rough, uneven, and serrated, is called the *nasal notch* The *upper margins* of the nasal bones and of the frontal processes of the maxillae imbricate, like shingles, upon the beveled portion of the nasal notch

From the center of the nasal notch, the *nasal process* projects downwards and forwards underneath the upper margins of the nasal bones and the frontal process of the maxillae The *frontal spine* extends below farther than the nasal process itself, and it becomes fused with the perpendicular plate of the ethmoid posteriorly, and with the septal crests of the nasal bones anteriorly to give the bridge of the nose a solid support

This type of construction makes infracturing difficult and inadvisable Out-fracturing is the procedure to be chosen

If, to complete an osleotomy, a chisel is used to fracture at the nasion, the surgeon should bear in mind that this technique may cause fractures of the sloping edges of the nasal notch, of the frontal spine, of the perpendicular plate of the ethmoid, destroying the main support of the nasal bridge, and the impact of the chisel may even be transmitted to the cribriform plate, furthermore, when the frontal sinus extends below the fronto-nasal suture line, which is located at the

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*Read at the meeting of the Eastern Section American Laryngological Rhinological and Otological Society Inc. Philadelphia Pa. Jan 9 1958

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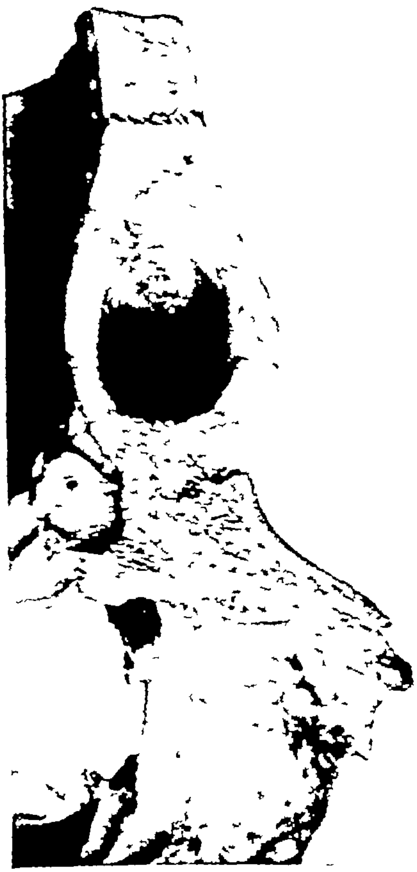


Fig 2 Under-developed frontal sinus The floor of the frontal sinus is about 2 cm above the upper ends of the nasal bones A solid block of bone is found where the sinus is normally located

nasal walls, it turns downward, outward and backward, pointing directly to the inner canthi of the eyes (see Fig 2)

## THE PRE-LACRIMAL GROOVE

One of the most important landmarks of the nasal pyramid is the inner rim of the orbit This is essentially the anterior lacrimal crest Adjacent to it, medially, is a groove which is semi-lunar in shape and runs parallel to the inner orbital rim We shall call this groove the pre-lacrimal groove (sul-

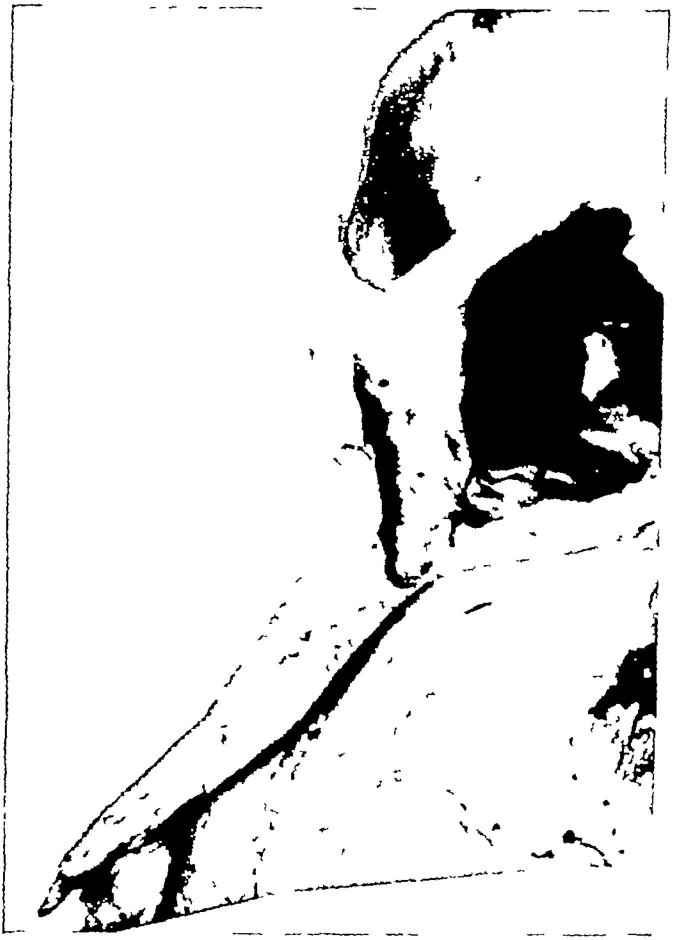
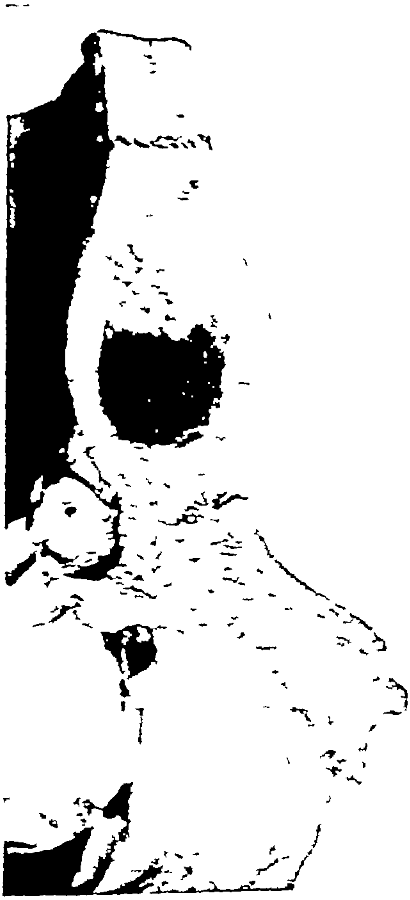


Fig 1 Over-developed frontal sinus The floor of the frontal sinus is about 3 cm below the upper ends of the nasal bones which become part of the anterior wall of the sinus

Before rhinoplastic surgery is considered, X-ray studies of this region should be made These should include the frontal sinus, the nasal bones and the frontal processes of the maxillae The naso-frontal suture line should be mapped out, and its relationship *to the frontal sinus and to the above-described* block of bone should be determined This suture line originates at the nasion, where it runs straight across the upper limits of the nasal dorsum and, when it reaches the lateral



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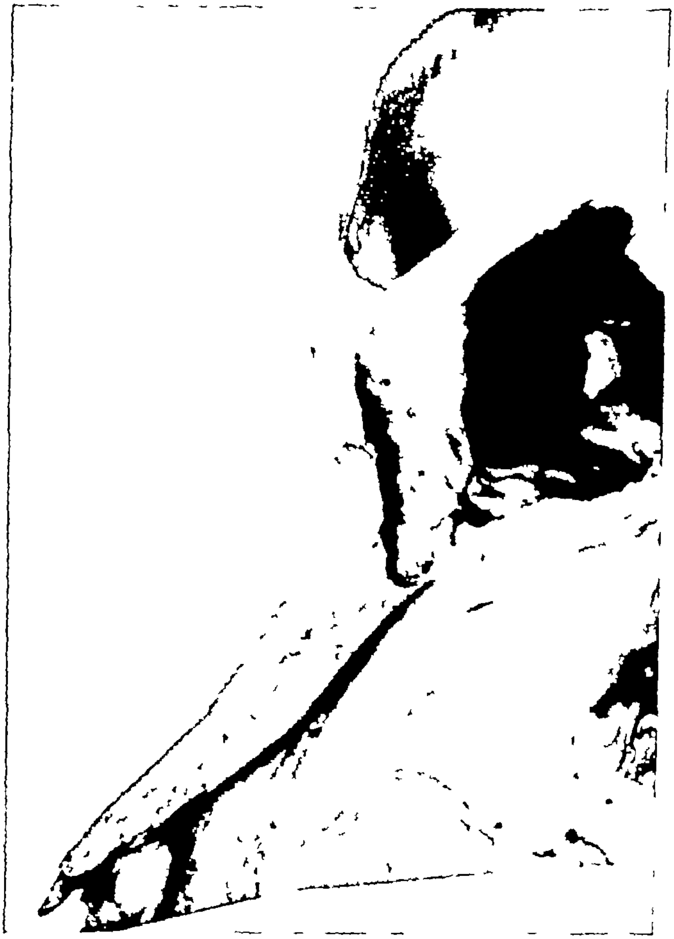

*Fig 1 Over-developed frontal sinus The floor of the frontal sinus is about 3 cm below the upper ends of the nasal bones which become part of the anterior wall of the sinus*

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# THE USE OF ANTIBIOTIC-STERIOD COMBINATIONS AS NEBULIZING AGENTS IN THE TREATMENT OF LARYNGEAL CONDITIONS

## A Preliminary Report *

BERNARD L. SILVERBLATT, M.D.,

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The treatment of disease entities affecting the larynx is predominantly surgical. Except for antibiotics in the acute infectious reactions and streptomycin in tuberculous laryngitis, other therapeutic measures have failed to produce the enthusiastic results portrayed by their author. Thus podophyllin, hormonal agents as theelin, adrenalin, etc., are seldom prescribed today. Limitations of vocal abuse, smoking and alcohol, persist as standard directives to the patient with hoarseness.

For almost two years, we have been using antibiotic steriod combinations in the treatment of many of our laryngeal problems. This combination has been used in nebulization form, both as a primary therapeutic agent and as an adjunct to surgical procedures. We feel that the combination has rational and merit for usage. I would stress, however, that they are not "cure-alls."

### ANALYSIS OF THE PROBLEM AND RATIONAL OF THERAPY

Standard textbooks list[1] better than 50 specific diseases of the larynx. Standard nomenclature increases this to better than 150 diagnoses. This discrepancy is partially due to our own inadequacies in standardizing nomenclature for disease entities; thus a clinical entity may be diagnosed on the basis of the etiology, the pathologic picture, the anatomic deformity or disability, and with the name of an author.

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cus pre-lacrimalis) This landmark is important, because it indicates the posterior limits of rhinoplastic surgery

Posterior to this groove are found the following vital structures the lacrimal sac, the naso-lacrimal duct, the orbital contents, the agger nasi cells, the middle turbinate, the cribriform plate and the naso-frontal duct

## SUMMARY

*1* The frontal sinus may be over-developed and extend downwards beyond the glabella, past the fronto-nasal suture line, reaching as far down as the middle of the nasal bones The nasal bones themselves will then become part of the anterior wall of the frontal sinus, and the floor of the sinus will be attached directly to the inner surfaces of the nasal bones

*2* The frontal sinus may be under-developed and stop short of the glabella In this instance, a solid block of compact bone will be found where the sinus is normally located X-ray studies will determine the relationship of the frontal sinus to the nasal bones

*3* The nasal notch of the frontal bone is beveled, at the expense of the outer layer, to form a suitable bed for the imbrication of the upper edges of the nasal bones and of the frontal processes of the maxillae The frontal spine extends further downward from the center of the nasal notch, to become fused with the septal crests of the nasal bones and with the bony septum, to give the nasal bridge greater support This construction makes infracturing impracticable

*4* The pre-lacrimal groove (sulcus pre-lacrimal) is one of the most important landmarks of the nasal pyramid It is located between the inner orbital rim and the postero-lateral margin of the nasal pyramid It runs parallel to the inner orbital rim, and it is semi-lunar in shape It can easily be felt by digitation This groove indicates the posterior limits for rhinoplastic surgery There are no vital structures anterior to this groove, they are all posterior to it

2054 Locust Street

## CLINICAL RESULTS

Antibiotic-steroid nebulization has been utilized in the clinical management of all of these conditions The antibiotic to combat the infectious factor in the etiology of many of these conditions, or the secondary infection that may co-exist, the steroids to act as the blocking or anti-inflammatory agent for the stereotyped reaction that occurs in response to nonspecific irritation In its action it also controls fibrosis of healing

### ACUTE LARYNGITIS

*Case 1* Young male employed in recapping automobile tires developed hoarseness when the overhead ventilator broke down and he was subjected to the inhalation of concentrated chemical irritants, symptoms had persisted for one week Examination revealed a diffuse redness of the larynx with edema of the mucosa Nebulization therapy was recommended Report of the referring laryngologist 48 hours after therapy was "improved voice with marked clearing of the local reaction '

### ACUTE LARYNGITIS

*Case 2* Young male railroader was seen in consultation because of hoarseness and painful difficult swallowing, four weeks prior he had been injured and exposed to chemical fumes when a Diesel engine exploded Treatment during his two weeks of hospitalization consisted of penicillin and confinement in an oxygen tent, at this time the mucosa of the hypopharynx and larynx was red and edematous there were residual areas of ecchymosis and ulceration in the nasopharynx One week after nebulization therapy was started the voice had improved and pain and difficulty in swallowing had subsided In another week all symptoms had subsided and the physical findings had returned to normal

Both cases represent specific therapy for a reversible process

The contact ulcer has usually been a chronic difficult problem to treat

*Case 1* Music teacher with hoarseness for two weeks failed to show improvement under a regime of therapy prescribed by her home town laryngologist Examination of the larynx showed a diffuse edematous ulceration with exudate on the right vocal cord and a concave ulceration of the right arytenoid One week after nebulization there was 75 per cent improvement the edema and exudate had subsided leaving only the concave ulceration of the vocal process, this was larger than on the original examination Two weeks later healing was complete, voice rest had not been insisted upon

*Case 2* A similar result was obtained in a female patient with hoarseness for two months excessive talking and smoking had been part of an unusually active social program there was a large ulceration of the right vocal process Two weeks after therapy the process was 50 per

If we analyze the laryngeal diseases, however, we find that they can be classified into six categories *1* Congenital Defects, *2* Infections, *3* Toxic, *4* Traumatic, *5* Paralysis, neuromuscular and systemic disturbances, *6* Tumors

Of these, congenital defects and paralysis can be eliminated from this discussion The others may be considered, since they have a common factor in that they represent an inflammatory reaction, using the term inflammatory as a non-specific reaction to injury whether due to infection, allergy, irritation or trauma The inclusion of tumors depends upon these factors *1* Many of the so-called benign tumors of the larynx are actually non-neoplastic in origin, *2* Malignant tumors are of unknown etiology and steroids, and antibiotics have been used to control neoplastic activity in other parts of the body, *3* Nebulization might be a useful adjunct in the postoperative healing program

The pathologic response to inflammation in the larynx is the same as elsewhere in the body, differing only in the symptomatology of the local anatomy The inflammatory reaction takes place in the subcutaneous connective tissue[2,3] This reaction leads to progressive changes, described from the gross appearance, as redness, edema, hyperplasia, fibrosis or hypertrophic changes with keratosis For simplicity we can diagram this gross pathologic picture and coordinate it with our clinical diagnosis as follows

| GROSS APPEARANCE | | CLINICAL DIAGNOSIS |
|---|---|---|
| Redness<br>↓<br>Edema | Reversible | Laryngitis<br>↓ Contact Ulcer<br>Hyperplasia Polyp<br>↓<br>Vocal Nodule<br>Papilloma |
| Fibrosis<br>↓<br>Metaplasia | Irreversible | Pachydermia<br>Hyperkeratosis<br>Leukoplakia<br>Cancer |

was started and endoscopic removal performed in February and April There was no recurrences at the last examination in November

## HYPERKERATOSIS AND LEUKOPLAKIA

Nebulization has been used both as a primary therapeutic agent and also as a postoperative adjunct in these cases The progress of therapy can be observed in the routine examination of the patient We feel that we have been able to reverse the process in cases with early surface changes, and prevent recurrence in those cases requiring endoscopic removal

## TUMORS

Nebulization has been utilized in the postoperative care of patients with carcinoma *in situ* removed under direct laryngoscopy

## METHOD OF THERAPY

A No 40 DeVilbiss nebulizer is prescribed for home use by the patient The preparation of choice has been cortisporin This is a suspension of aerosporin, neomysin and hydrocortisone in an aqueous vehicle Therapeutically this formula combats infection due to susceptible organisms, and relieves symptoms caused by an inflammatory process The incidence of tissue sensitivity to the components is low While other preparations may be equally effective, we believe that a suspension offers the advantage of a greater concentration and more prolonged action

The patient is instructed in the method of nebulization and treats herself four times daily with 6 to 8 inhalations at each procedure Therapy is decreased to an "as needed regime," with improvement in symptoms and local findings

## SUMMARY

An analysis and rational for the use of cortico-steriod-antibiotics combination in various disease entities of the larynx has been presented The clinical results observed in the treatment of various laryngeal diseases with cortisporin cent improved in spite of continuation of her social activity Because of her apprehension, therapy was continued along with limited voice use One week later the voice and local findings were normal, and there has been no recurrence to date

*Case 3* S K, age 42, was a salesman with hoarseness for two years, a laryngoscopy had been performed twice previously for removal of a tumor Our examination revealed the presence of a large pea sized granuloma of the right vocal process A recurrence developed after laryngoscopic removal Nebulization therapy was prescribed The patient was not seen again for three months At this time the voice was good and laryngeal examination revealed complete healing with only a small epithelized nodule at the site of the previous granuloma

## LARYNGEAL POLYP

The laryngeal polyp is basically a localized edematous reaction It is referred to by clinicians and pathologists in varying descriptive terminology Nebulization has been used as the primary agent in many cases, with a satisfactory reversal of the process and improvement in the voice In other cases treatment has been used as a postoperative adjunct to prevent irreversible granulation We feel that there have been benefits in both situations

## PAPILLOMA

Papilloma has been a problem, especially in children, because of its tendency to recur Improvement with antibiotic therapy has been controversial We feel that the antibiotic steroid combination has served to abort the process when used as a postoperative adjunct

*Case 1* R M, age five years, was first seen in 1954 A tracheotomy had been performed at the age of two years, and endoscopic removal of papilloma performed repeatedly Laryngeal findings at this time were described as a diffuse growth of papillomas in the larynx and extending into the upper segment of the trachea During 1954 and 1955 we continued to remove papillomas every three months Nebulization therapy was added to his regime in April, 1955 There was complete arrest of the recurrence, so that in October, 1955, the tracheostomy was closed There was no recurrence at the last examination in September, 1957 Age at this time was seven years

*Case 2* A. B, age three years was first examined in 1955 with hoarseness due to a diffuse growth of laryngeal papilloma over both cords Endoscopic removal was performed at three-month intervals until February, 1957 when nebulization therapy was started Papillomas were removed in July, 1957, and there has been no recurrence to date Patient is now five years old

*Case 3* J H, age three years had papillomas removed on three occasions prior to our examination in February, 1957 Nebulization therapy

# THE ROUTINE BLEEDING AND CLOTTING TIME TESTS: THEIR MEDICOLEGAL STATUS*†

RUSSELL FLETCHER, M.D.,
San Rafael, Calif.

The reason for presenting a paper on this controversial subject is to review briefly the history of the tests and the reasons why these obsolete "screen" tests are so extensively employed. The modern diagnosis of hemorrhagic disease leaves no doubt that these tests are not accurate, they are not reliable, and actually they may constitute a danger or a menace to the patient and to the physician by inducing false security if he relies upon these tests alone to determine preoperatively whether or not a patient will bleed.

## THE HISTORY OF THE BLEEDING AND CLOTTING TIME TESTS

These tests have been done for 40 years. Bailey[1] in 1922, and Hunt[2] in 1927, each made surveys of several hundred hospitals in the United States in which a large percentage used the tests routinely. They found that most of the hospitals and physicians who had stopped using the tests did so because they were not reliable. Hunt stated that it was not necessary to have tests done if a proper history and physical examination had been done. Shepeard[3] in 1948, stated that the tests were "a vestigial remnant of yesteryear," and the *Journal of the American Medical Association*,[4] in 1955, commented on his article as follows: "There have been numerous reports relating experience from Nose and Throat Departments that show bleeding and clotting time estimates are not practical as tests predicting hemorrhages during and after a tonsillectomy. Normal results are not a guarantee of freedom from hemorrhage, and abnormal results have been ob-

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*Read at the meeting of the Western Section, American Laryngological, Rhinological and Otological Society, Inc., Beverly Hills, Calif., Jan. 18, 1958.

†The blood taken for these tests is taken from a puncture wound of the finger or ear and is not done routinely by venepuncture.

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nebulization as a primary agent and as an adjunct to surgery have been reported

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## ANNUAL OTOLARYNGOLOGIC ASSEMBLY UNIVERSITY OF ILLINOIS

The University of Illinois College of Medicine Department of Otolaryngology announces its Annual Otolaryngologic Assembly from September 29 through October 5, 1958 The Assembly will consist of an intensive series of lectures and panels concerning advancements in otolaryngology, and evening sessions devoted to surgical anatomy of the head and neck and histopathology of the ear, nose and throat Interested physicians should write direct to the Department of Otolaryngology, 1853 West Polk Street, Chicago 12, Ill information, as well as the fact that practically all physicians concede that the tests are of very little value, why are these tests done in so many hospitals, either optionally on the part of the physicians, or are required by hospital regulations? In a rough survey of the hospitals of the San Francisco Bay area, over 50 per cent of them require these tests preoperatively In Portland, Ore, seven of the eight hospitals have the tests done

## REASONS GIVEN FOR CONTINUING THE TESTS

*1* An occasional physician "thinks that the tests might be helpful sometime" (rarely is there a physician found who is convinced of this fact) *2* Some physicians believe that having the tests done reassures the patient *3* Many physicians, when asked why they continue the test, answer "why worry or fuss about eliminating the tests which cost the patient such a trivial or paltry sum" ($2 00 in the San Francisco Bay area), and they add, "anyhow, most patients have insurance" Although economics should never be a consideration in this problem, it is one of the chief arguments of the proponents for continuing the tests A few facts might be brought out regarding this If it is not reliable and not necessary, it is wasteful, no matter how cheap it is or who pays for it

In Marin County, with a population of 30,000, the three hospitals in this county did 5,446 operations in 1957 At $2 00 per test, this amounts to $10,892 As Marin County is approximately 1 per cent of the State of California, this total would be $1,089,200 for the State If this amount is wasted by requiring an unnecessary test, it is not trivial or paltry One of the health insurance companies in California that does 10 per cent of the health insurance in this State, handles about 90,000 operations per year, therefore, it is self-evident that elimination of such unnecessary tests would be a material saving to all insurance companies *4* The tests have been done for so many years that physicians are hesitant to discard "such time-honored tests," which is chiefly due to inertia The fact that any test has been done routinely by a large number of physicians in any community was a strong medicoserved without subsequent bleeding Dependence upon bleeding and clotting time tends to lead to a false sense of security The history and physical examination are much more important, *and if such an examination suggests a bleeding* tendency, then a thorough study is indicated"

There are some statements in the literature, and in text books, which claim in the same sentence that "although the tests are not reliable, their omission "might have disturbing medicolegal consequences" Some text books have stated that the tests were of value in anticipating hemorrhage pre-operatively (These indefinite statements and inferences in the literature, are the points that a lawyer grasps in order to convince a jury that one was negligent if the tests were not done) This is illustrated by our experience in Marin County this past year The surgeons voted unanimously to eliminate the tests pre-operatively, however, the pathologists, who direct all the hospital laboratories, strongly argued that, although they "conceded that the tests are of somewhat limited value," they felt that such statements and inferences as noted above in the literature were of sufficient value for the lawyer to accuse and perhaps convince a jury that there was negligence if the tests had not been done on a patient that subsequently hemorrhaged The result was that the hospital made it obligatory to have the tests done pre-operatively on every patient

The following are a few of the outstanding hospitals and clinics that do not have tests done pre-operatively the Massachusetts Eye and Ear Infirmary, the Children's Hospital in Boston, the hospitals in Baltimore, the University of Michigan Hospital, the Mayo Clinic, the University Hospital in Iowa City, and Stanford Hospital in San Francisco All of these hospitals had routinely used the tests for years, but abandoned them because they were not reliable

In a letter from the legal department of the American Medical Association,[5] dated Dec 13, 1957, it was stated that they knew of no court decision based upon the use or non-use of these tests

*Why are These Tests Still Continued?* In spite of the above all in-patients about to undergo surgery is a sensible one, and that it should not be changed *unless substantial medical evidence is available* as to the *unreliability* and *futility* of *the tests*", therefore, it is up to the medical profession to show "substantial medical evidence as to the unreliability and futility of the tests"

This evidence is available from three national authorities on hemorrhagic diseases *1* The most concise and graphic presentation of this evidence is given in a letter from Louis K Diamond, M D ,[c] who is Associate Professor of Pediatrics at Harvard Medical School, and who is in charge of the Blood Clotting Laboratory at Children's Hospital in Boston He made the following brief survey *Survey of children referred to the Blood Clotting Laboratory of Children's Hospital of Boston in the past four years*

*Group I* Patients who had had a routine pre-T and A bleeding and clotting time determination in a hospital laboratory where one or both tests were found to be prolonged beyond normal limits and, therefore, were referred to us for more elaborate tests which we found to be entirely normal, nine patients, most of whom later had T and A without any bleeding disturbance

*Group II* Patients who had a definite history of bruising in the past and when explored, frequently a history of bleeding in relatives, but normal bleeding and clotting times had been determined by routine methods, 14 patients, nine of whom had hemophilia of varying degrees and five Christmas disease

*Group III* Patients who bled following surgery, in whom a routine bleeding and clotting time was said to be normal, five patients, of whom four had hemophilia and one Christmas disease

*Group IV* Patients who bled following surgery in whom a good bleeding and clotting time test, even using venous blood, and supervised by our own laboratory, showed normal values, and yet following T and A in seven cases and dental extraction in one case, there was moderate to severe hemorrhage In two cases blood loss was sufficient to require transfusion legal argument for continuing the test This point is very well covered in the next paragraph, under *"Medicolegal Status."*

5 *The Mediolegal Status* The chief reason why physicians and hospitals have continued this routine pre-operative test is the medicolegal threat or intimidation that failure to have had the tests done might be grounds for negligence if a lawsuit were instigated because a patient hemorrhaged On the Pacific Coast we are particularly aware of malpractice suits This is reflected in the high rates for malpractice insurance The rates given by the American Academy of Ophthalmology and Otolaryngology shows that Oregon has the highest rate in the nation, which is about twice as high as California, and Washington which, in turn, are three times as high as the rates in Texas, Pennsylvania or New Hampshire, and twice as high as New York

What is the accepted or customary practice in the community in which you practice? A letter from the legal department of the American Medical Association to me,[5] dated Dec 13, 1957, outlines the requirements very well and states in part, as follows "To comply with legal requirements, a physician must meet the standards of good medical practice in any service he furnishes a patient These standards are based on what other reputable physicians in the community, or in similar communities, would or would not do in the care of similar cases One of the tests applied, so far as the use of a particular medical or surgical technique is concerned, is the *general reliability and acceptance of such technique* If the value of a particular technique is of such a degree that a substantial number of reputable physicians in the community would utilize it in a given situation, then the failure of a physician to utilize it in the same or similar situation would be a difficult factor to explain in a subsequent malpractice suit It may not constitute negligence *per se*, but the jury would certainly regard such factor with respect Whether or not bleeding and clotting time tests enjoy the degree of acceptability described above, I cannot say *That must be decided by the medical profession* I believe a hospital regulation urging routine bleeding and clotting time tests on all in-patients about to undergo surgery is a sensible one, and that it should not be changed *unless substantial medical evidence is available* as to the *unreliability* and *futility* of *the tests*", therefore, it is up to the medical profession to show "substantial medical evidence as to the unreliability and futility of the tests"

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*Group IV* Patients who bled following surgery in whom a good bleeding and clotting time test, even using venous blood, and supervised by our own laboratory, showed normal values, and yet following T and A in seven cases and dental extraction in one case, there was moderate to severe hemorrhage In two cases blood loss was sufficient to require transfusion legal argument for continuing the test. This point is very well covered in the next paragraph, under "*Medicolegal Status*."

5. *The Mediolegal Status.* The chief reason why physicians and hospitals have continued this routine pre-operative test is the medicolegal threat or intimidation that failure to have had the tests done might be grounds for negligence if a lawsuit were instigated because a patient hemorrhaged. On the Pacific Coast we are particularly aware of malpractice suits. This is reflected in the high rates for malpractice insurance. The rates given by the American Academy of Ophthalmology and Otolaryngology shows that Oregon has the highest rate in the nation, which is about twice as high as California, and Washington which, in turn, are three times as high as the rates in Texas, Pennsylvania or New Hampshire, and twice as high as New York.

What is the accepted or customary practice in the community in which you practice? A letter from the legal department of the American Medical Association to me, dated Dec. 13, 1957, outlines the requirements very well and states in part, as follows: "To comply with legal requirements, a physician must meet the standards of good medical practice in any service he furnishes a patient. These standards are based on what other reputable physicians in the community, or in similar communities, would or would not do in the care of similar cases. One of the tests applied, so far as the use of a particular medical or surgical technique is concerned, is the *general reliability and acceptance of such technique*. If the value of a particular technique is of such a degree that a substantial number of reputable physicians in the community would utilize it in a given situation, then the failure of a physician to utilize it in the same or similar situation would be a difficult factor to explain in a subsequent malpractice suit. It may not constitute negligence *per se*, but the jury would certainly regard such factor with respect. Whether or not bleeding and clotting time tests enjoy the degree of acceptability described above, I cannot say. *That must be decided by the medical profession.* I believe a hospital regulation urging routine bleeding and clotting time tests on hemorrhagic studies are not indicated in the case of patients who are not bleeding at the time, or who have a personal and family history negative for abnormal bleeding, and no signs of abnormality at the time of physical examination "

He further states "On patients whose history or physical examination indicates a bleeding tendency, then special hemorrhagic tests *by experts* are indicated" He stated that "a surgeon would not be considered negligent if he did not perform routine pre-operative tests for bleeding and clotting time" He also states "in the past, the finger tip method was an accepted and standard practice and afforded the surgeon, the laboratory director, and the hospital administration a degree of medicolegal protection which comes from the performance of the usual and customary procedures Such procedures will not, in the light of present knowledge, continue to be accepted" There are so many interesting and pertinent facts in this article by Dr Diggs, that it would take too long to review them in this paper It is, therefore, strongly recommended that everyone read this excellent article by Dr Diggs

## CONCLUSIONS

*1* The routine bleeding and clotting time tests are not reliable, authorative medical evidence is herewith presented (It has also been the experience of many clinicians)

*2* The tests are dangerous and a menace to the patient and to the physician by inducing a false sense of security

*3* The safest practice for the patient, as well as the physician, is to take a careful history of bleeding in the patient and the family, and to make a good physical examination If these show any bleeding tendency, then special hemorrhagic studies *by an expert* are indicated

*a* A physician with such a patient will not be guilty of negligence if the routine tests were not done pre-operatively and the patient subsequently bled

*b* A physician with such a patient who relied on the routine bleeding and clotting tests *alone* and did not have special

2. The second authoritative evidence is given by Paul Aggeler, M.D.,[7] Associate Clinical Professor of Medicine at University of California Medical School, and Head of the Blood Clotting Research Laboratory at Children's Hospital in San Francisco. He states that "numerous cases falling into all four categories listed by Dr. Diamond have been extensively investigated in his laboratory. During the past three years alone, 28 patients whose bleeding and venous blood clotting time were normal, were nevertheless proven by more detailed methods to suffer from well defined clotting disorders (hemophilia, P.T.C. deficiency, P.T.A. deficiency, hypoproconvertinemia and fibrinogenopenia). In about one-third of these patients tooth extraction, tonsillectomy, and even major surgery had been performed, with hemorrhagic complications in every instance. In several cases, because of the false assurance afforded by normal bleeding and clotting times, the operation had been done without further investigation, despite the surgeon's complete awareness of the bleeding history. In 20 years' experience in this field Dr. Aggeler can recall not a single instance in which a bona fide hemorrhagic disorder was discovered solely by the use of routine pre-operative bleeding and clotting times. He has seen many cases, however, where false positive results have lead to still further useless and expensive investigations."

3. The third source of evidence that these tests are not reliable, is the article "Diagnosis of Hemorrhagic Diseases—Evaluation of Procedures." Part I appears in the December, 1957, *California Medicine*, and Part II in the January, 1958, issue by L. W. Diggs, M.D., who is Professor of Medicine at the University of Tennessee College of Medicine, and Director of Department of Medical Laboratories, University of Tennessee, City of Memphis Hospitals, who was the guest speaker at the California Medical Association meeting in May, 1957, in Los Angeles. This paper discusses in detail the importance of a careful history and physical examination, and states that "they are more reliable than laboratory tests for the prediction of the tendency to bleed at the time of surgical operation, and failure to obtain a history of bleeding episodes may be catastrophic." He also states that "Routine pre-operative

# THE TREATMENT OF POLYPOID LARYNGITIS *†

GERSON LOWENTHAL, M D ,

Cincinnati, Ohio

The term polypoid laryngitis designates a localized or diffuse non-specific inflammatory tumor of one or both vocal cords, involving the epithelium and the subepithelial space of Reinke This space is a very thin layer of loose connective tissue between the epithelium and the elastic and muscular tissue of the vocal cords[1] It extends from near the anterior commissure to the vocal process of the arytenoid and to the stria arcuata, superior and inferior,[2] which is the transition point between the squamous and the columnar epithelium above and below It has a scarce arterial supply but a rich venous plexus The epithelium is much thinner, only two or three layers, at the free edge and upper surface of the cord, while there are 10 to 20 layers of stratified squamous epithelium over the remainder of the cord[3] This explains why the inflammatory lesions may be restricted to this space, and why they occur most commonly along the phonating edge and upper surface of the cord

The most common inciting factors for polypoid laryngitis are considered to be the trauma of vocal abuse[4] or the irritation produced by smoking[5,6] These lesions nearly always produce hoarseness, tiring of the voice, occasionally pain or discomfort in the throat, and rarely, respiratory embarrassment Psychologically there is usually apprehension on the part of the patient over the implications of the symptoms

Clinically, the lesions may be placed in two groups localized and diffuse Either of these may be acute, due to sudden vocal strain, or chronic, due to repeated trauma to an unresolved process In the localized, the tumor may be a pedun-

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†From the Departments of Otolaryngology The Jewish Hospital and The College of Medicine University of Cincinnati Cincinnati Ohio

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hemorrhagic tests by an expert, might be accused of negligence

4 Since the tests have been proven to be so unreliable, they should not be required pre-operatively on surgical patients

5 "If it is medically sound, it will stand up legally!"[9]

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1010 B Street

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## POST GRADUATE COURSE
## UNIVERSITY OF ILLINOIS

The next postgraduate course in Laryngology and Broncho-esophagology to be given by the University of Illinois College of Medicine is scheduled for the period October 27 through November 8, 1958, *under the direction of* Dr Paul H Holinger

Interested registrants please write to Department of Otolaryngology, *University of Illinois College of Medicine*, 1853 West Polk Street, *Chicago* 12, *Illinois* neoplasm, benign or malignant, not only in gross appearance but also in mode of onset and in production of symptoms" They feel that with few exceptions all benign tumors should be removed

Although the definition, clinical appearance, etiology, histopathology and location may be variable or controversial,

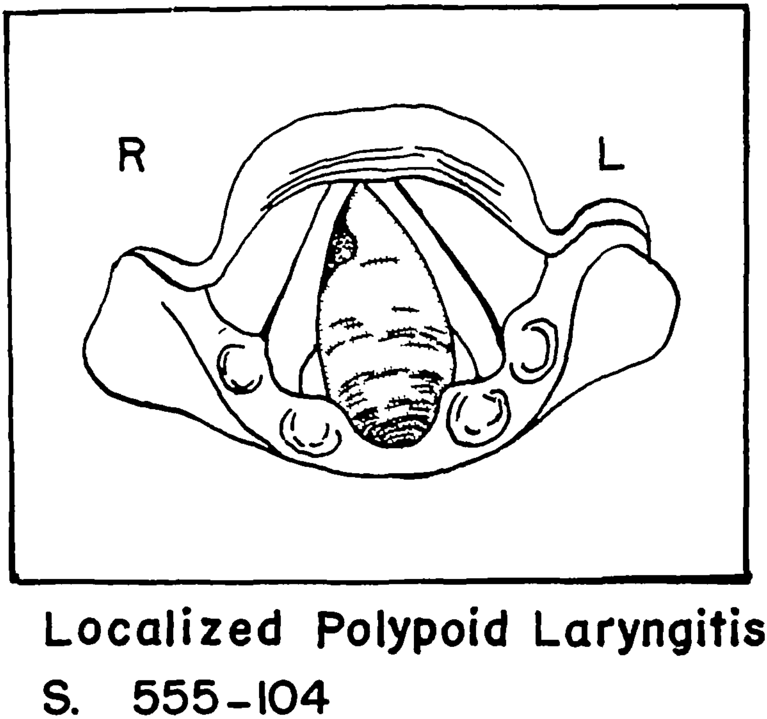

Fig 2 Most common location on cord—the anterior half (View by indirect laryngoscopy)

there is relative unanimity with regard to treatment This paper will concern itself primarily with the surgical treatment

Treatment is divided into three phases first, the medical or "expectant" phase A careful survey of the mouth, ears, nose and throat, and a thorough medical examination to rule culated or sessile mass arising from the free edge or upper surface of the cord, near the junction of the anterior and middle thirds, rarely in the posterior third Occasionally the lesion may be found in the anterior commissure, and infrequently in the posterior commissure It may vary in color from a pale glistening gray to a pink, yellow or purple In consistency it may vary from soft, almost gelatinous, to rather firm and nodular In the diffuse, the swelling involves the

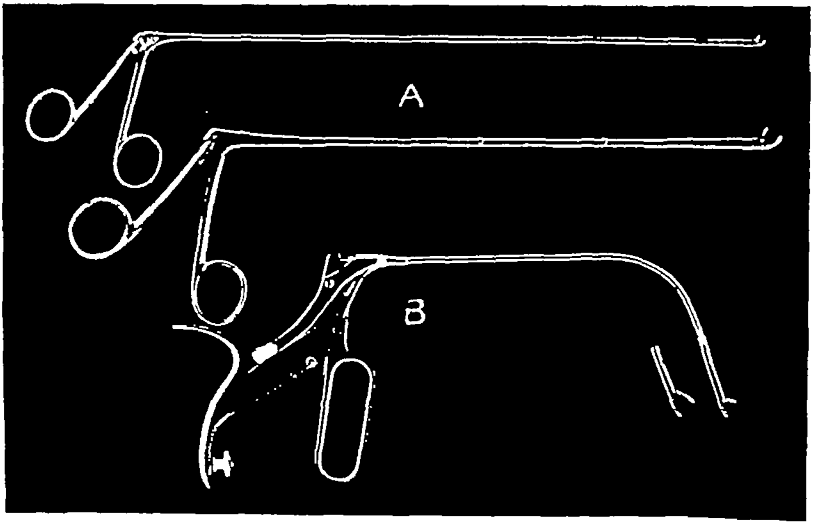

Fig 1 Instruments used in surgical treatment of polypoid laryngitis A Jackson Laryngeal Cup Bite Forceps Angular Jaw 2-4 mm (Direct Laryngoscopy) B Curved Laryngeal Forceps (Universal Handle) 3-4 mm (Indirect Laryngoscopy)

anterior half or two-thirds or more of one or both cords The color may vary from a pearly gray to a dusky pink This type may also be flabby or somewhat firm

Histologically, the localized and the diffuse lesions frequently cannot be differentiated and show varying degrees of congestion, edema, thrombosis and hyalinization, described by Friedberg and Segall[3] (see Fig 4)

New and Erich,[2] in their monumental paper on benign tumors of the larynx, state that "Inflammatory tumors may bear an exact similarity to almost any type of laryngeal

Chlorophenol If the lesion is reversible within a few weeks, no further treatment may be necessary

The second phase is surgical treatment, which is essentially an excisional biopsy (see Fig 3), with gentle, precise, superficial removal of the lesion It is well recognized that following this principle without damage to the underlying elastic membrane, there appears to be complete regeneration of the cord with normal appearance and function This has been demonstrated by Jackson, Tucker,[11] Lore,[10] Holinger[12] and others[13] Jackson[15] states that it is better to leave a convex edge of the lesion on the cord, even if this should allow a little of the basal tissue to remain, rather than to remove too much tissue, leaving a concavity If necessary, a secondary procedure can be done In polypoid lesions with a suggestion of hyperkeratosis or leukoplakia, biopsies must be taken from various areas in the larynx and carefully labeled as to the site of origin of each specimen Thus, early or *in situ* carcinoma can be localized[14]

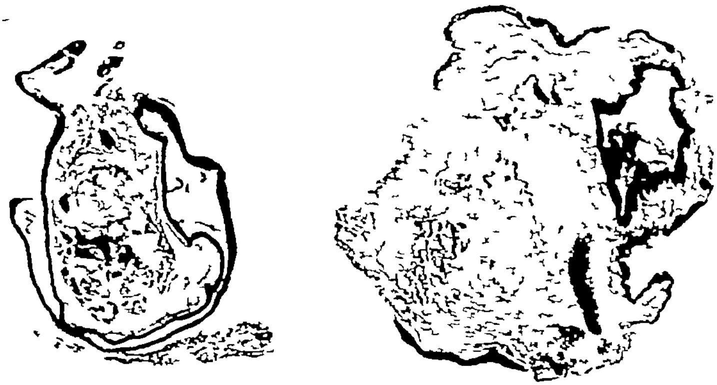

Fig 4 Localized Polypoid Laryngitis Photomicrograph of specimen shown in Fig 3 demonstrating congestion edema thrombosis and hyalinization of the loose subepithelial connective tissue

The recognized methods of surgical removal are by indirect[5] or direct[12] laryngoscopy under local or general anes-

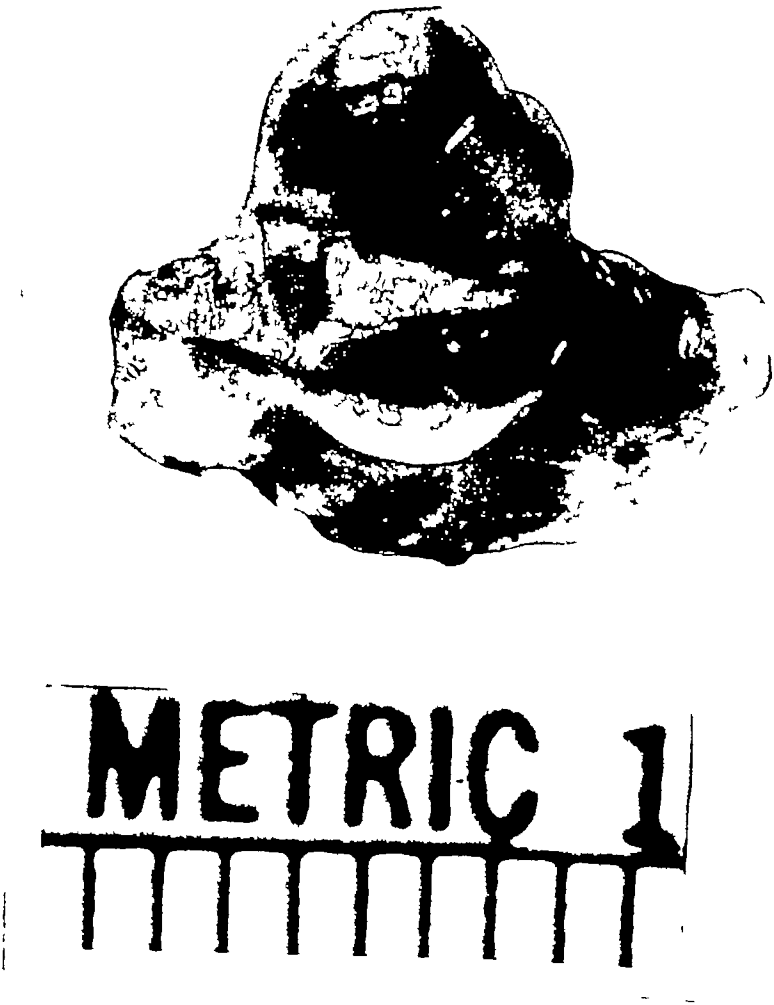

Fig 3 Localized Polypoid Laryngitis Photograph of a lesion removed from position shown in Fig 2

out local or pulmonary, or other systemic disease, is important[8] Elimination of the inciting causes such as vocal abuse, smoking, and alcohol ingestion, are mandatory Voice re-education is required in many cases Specific medical therapy has not been available, although recently steroids have been used by Brodnitz[9] Some symptomatic relief may be obtained from a bland intratracheal instillation such as Mono-P-

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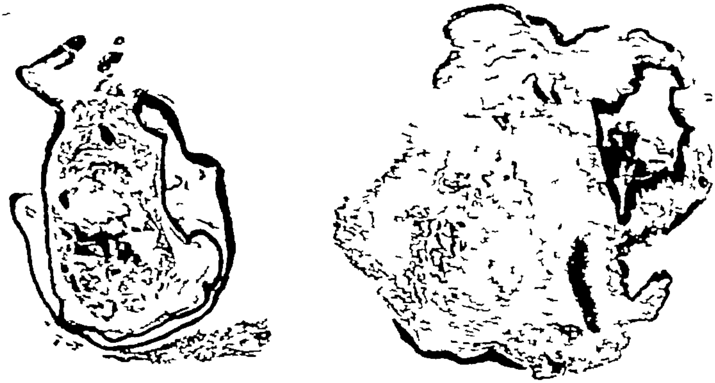

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demonstrated by Jackson, Tucker,[11] Lore,[10] Holinger[12] and others[13] Jackson[15] states that it is better to leave a convex edge of the lesion on the cord, even if this should allow a little of the basal tissue to remain, rather than to remove too much tissue, leaving a concavity If necessary, a secondary procedure can be done In polypoid lesions with a suggestion of hyperkeratosis or leukoplakia, biopsies must be taken from various areas in the larynx and carefully labeled as to the site of origin of each specimen Thus, early or *in situ* carcinoma can be localized[14]

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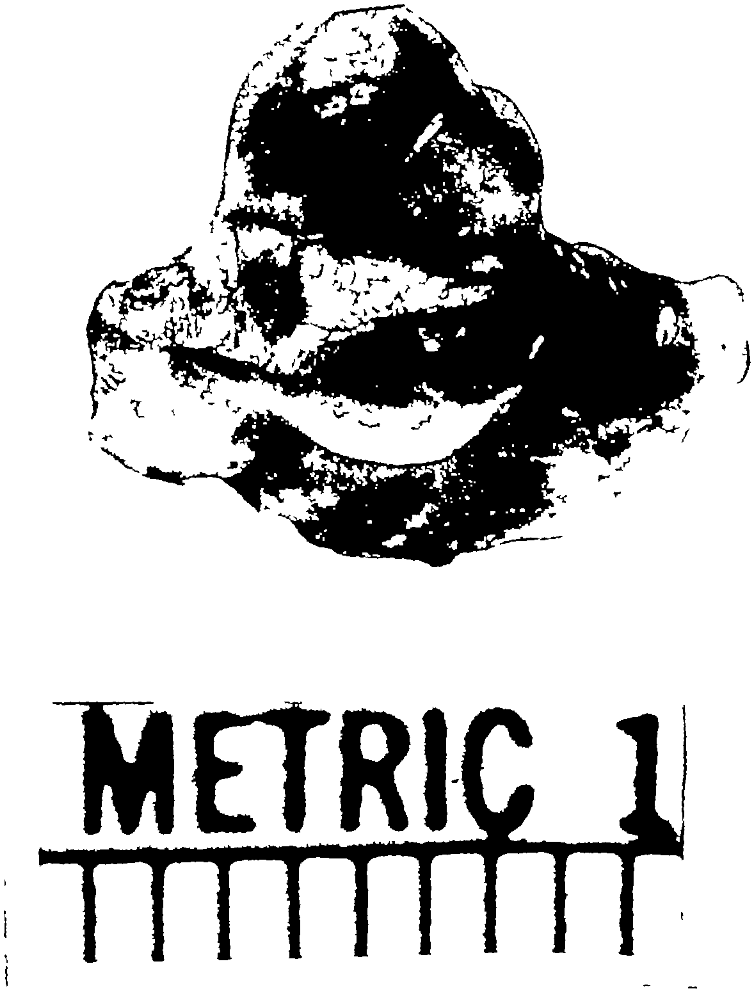

Fig 3 Localized Polypoid Laryngitis Photograph of a lesion removed from position shown in Fig 2

out local or pulmonary, or other systemic disease, is important[6] Elimination of the inciting causes such as vocal abuse, smoking, and alcohol ingestion, are mandatory Voice re-education is required in many cases Specific medical therapy has not been available, although recently steroids have been used by Brodnitz[9] Some symptomatic relief may be obtained from a bland intratracheal instillation such as Mono-P-three-minute intervals, and the patient is encouraged to expectorate the excess Some of the anesthetic is applied to the upper gum to reduce the discomfort of the laryngoscope later

Cocaine hydrochloride, 5 cc of 10 per cent solution, is freshly prepared in the operating room from a measured amount of crystals This is instilled into the laryngopharynx and larynx by the drop method Using a laryngeal syringe with a curved tip, several drops are placed into the valleculae and into each piriform sinus The patient is instructed to breathe quietly while the tongue is being held, after which he expectorates the excess and the procedure is repeated One cc is then instilled over the cords with the patient saying "A" or "E" for a few moments This is also repeated in a few minutes Rarely is more than 3 or 4 cc of the solution required

The combined technique is used most often First, by indirect laryngoscopy the lesion is removed by evulsion with a double cupped biting forceps The patient is usually unaware that this maneuver is different from the instillation of the anesthetic Depending upon the size of the lesion, a large or small tip is used Most, if not all, is removed by this technique

Secondly, a direct laryngoscopy with a Jackson or Holinger anterior commissure laryngoscope, using the Andrews chest support, or more recently, the Lewy[17] holder, is performed with the patient in the supine position, placing a folded blanket under his shoulders Direct laryngoscopy allows closer inspection of the lesion, and permits trimming of small, loose fargments of mucosa with a small angulated cupped forceps

Multiple and diffuse lesions are removed except when the anterior third of both cords are involved, (see Figs 2, 3, 4), then, the more severely involved side only is operated upon The polypoid cord on the other side is compressed or pinched with-the double cupped forceps in two or three areas to reduce the edema This may be a form of superficial scarification (see Fig 5) It was noted that in a number of patients a subsequent procedure on the second cord was obviated by this thesia, or by suspension[16] laryngoscopy under general anesthesia Rarely, an external approach with tracheotomy may be necessary for removal of a large growth[16] The surgical treatment in the series of cases analyzed was by indirect laryngoscopy, direct laryngoscopy, and most frequently by a combination of the two, under local (topical) anesthesia The operation is simple, orderly, and relatively easy on the patient For a successful procedure it is necessary to secure the cooperation of the patient, and to obtain good anesthesia Since the lesions under discussion occur most frequently in adults, this can usually be accomplished

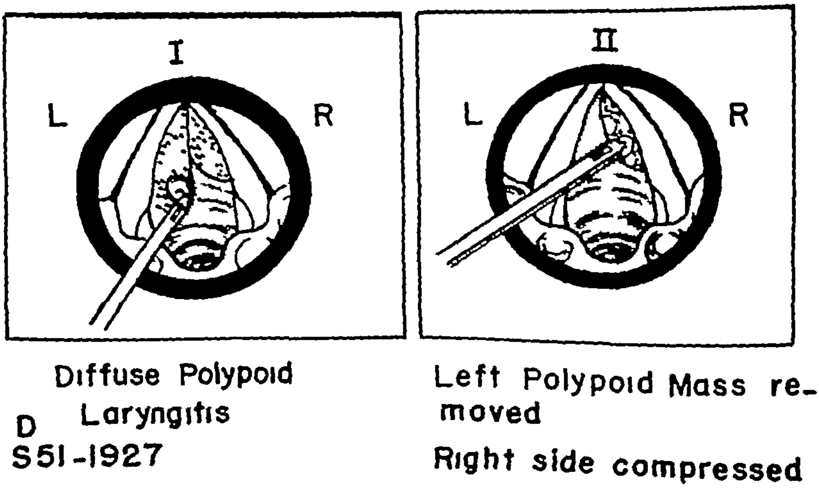

Fig 5 Diffuse Polypoid Laryngitis Bilateral Histologically these lesions are similar to the one shown in Fig 4 I and II—Steps in the surgical treatment (Direct laryngoscopic views)

Premedication consists of seconal or nembutal, grains $\frac{3}{4}$ to grains $1\frac{1}{2}$, taken at bedtime the night before surgery and repeated one hour pre-operatively Morphine sulfate, grains 1/8 to grains 1/6, and scopalomine, grains 1/300 to grains 1/200, are given hypodermically one-half hour pre-operatively

The mouth, oropharynx and hypopharynx are sprayed with 2 per cent pontocaine solution two or three times at about to remove further tissue In one instance there was a recurrence of a lesion on the same cord three years later The second lesion, however, occurred at the junction of the middle and posterior thirds, whereas the original was at the junction of the anterior and middle thirds The lesions also varied somewhat, the first being a polyp and the second a cyst In nine patients with bilateral diffuse polypoid degeneration of both cords, only three required operation on the second side after use of the compression (scarification) technique In one, with only slight diffuse involvement of the second cord, the compression technique was not necessary, and this patient also made a good recovery

## SUMMARY AND CONCLUSIONS

*1* The particular structure of the subepithelial space of Reinke predisposes to the formation of laryngeal polyps on the vocal cords

*2* In the series presented, as in other series, the most common benign tumors are inflammatory, and of these the localized polyps are the most frequent

*3* Treatment is divided into three phases the medical or "expectant", the surgical, wherein under local (topical) anesthesia, combined indirect or direct laryngoscopy is performed in all cases, the post-surgical, with removal of the initial predisposing factors and voice correction therapy if required

*4* In diffuse polypoid involvement of both cords, the larger lesion is removed The smaller lesion is compressed (superficially scarified) in two or three areas with a double cupped forceps This frequently obviates the need for surgery on the second cord

*5* In general, the prognosis in these lesions is good Recurrences are uncommon

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technique *Tschiassny[18] states that scarification is an old treatment and attributes the idea to Hajek Waldapfel[1] reported the use of "simple, superficial scarification of flabby tissue" in such a case, with complete resolution of the lesion without visible scar formation 1940

The third phase is post-surgical This consists of complete vocal rest for a period of 10 to 14 days, followed by a regime of sparing the voice for a period of several weeks and by voice correction therapy, if indicated This phase also includes the removal of the factors which predisposed to the lesion initially At the conclusion of the third phase the cords appear to be well healed and the voice returns to normal Recurrences are uncommon

The case histories reviewed for this paper are of patients over 20 years of age who failed to respond to the medical or "expectant" treatment described in phase one and, therefore, required surgical intervention This group consisted of 62 adult private patients operated upon for benign laryngeal tumors during the past ten years It is interesting to note that even in this small series there was a general distribution of lesions comparable to the vastly larger series reported by New and Erich,[7] and by Holinger[12] Polypoid tumors predominated in the small group, as they did in the larger series Thirty-five of the lesions were polypoid tumors, of which 26 were localized polyps and nine showed diffuse polypoid degeneration of both cords Six were papillary tumors, six were *multiple papillomata, there were three* angiomas, one hemangioma, two granulomas, three amyloid tumors, one leukoplakia, two cysts, two thrombosed varices and one vocal nodule In six instances other than the papillomata there were multiple localized lesions, sometimes of different types

In spite of the variation of diagnoses of these benign tumors and of their neoplastic and non-neoplastic character, the treatment of this entire series was essentially the same Following surgery the cords healed well and appeared normal, and the voice returned to normal within a period of several weeks In only two cases was it necessary to go back a second time

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*He suggests that diffuse lesions be known by the descriptive term 'subepithelial chronic edematous corditis

## SUBCOMMITTEE ON HEARING IN CHILDREN

The American Academy of Ophthalmology and Otolaryngology, through its Subcommittee on Hearing in Children of the Committee on Conservation of Hearing, has been conducting a long-term nationwide study of problems relating to the conservation of hearing in children The specific aims are to develop the most efficient case-finding methods and to use these methods in estimating the magnitude of the problem in the country, to study state laws and review current practices and facilities for rehabilitation of hearing impaired children, to help develop methods for medical and surgical rehabilitation standards, and ultimately to use the Subcommittee findings in assisting professional workers to improve and enhance programs in hearing loss

In the second year of operations, a full-time Executive Director has been engaged, and offices established at the Graduate School of Public Health, University of Pittsburgh An initial study is being conducted in Pittsburgh to identify early medical signs and symptoms which may indicate danger of hearing impairment, to measure the psychological, social and other effects of such impairment and to develop efficient and economical methods for the testing of hearing in children The Pittsburgh study is a cooperative effort among the following The Subcommittee on Hearing in Children, the Graduate School of Public Health and the School of Medicine of the University of Pittsburgh, the Pittsburgh Board of Public Education, and the Allegheny County Department of Health.

The members of the Subcommittee on Hearing in Children are Dr John E Bordley, Baltimore, Dr Victor Goodhill, Los Angeles, Dr Hollie E McHugh, Montreal, Dr S Richard Silverman, St Louis, and Dr Raymond E Jordan, (Chairman) Pittsburgh An advisory committee of consultants from the University of Pittsburgh includes Dr Samuel M Wishik, Dr Leo G Doerfler, and Dr Isidore Altman Grants from the United States Children's Bureau through the Pennsylvania Department of Health and from the National Institutes of Health are providing financial support

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# PROGRAM OF THE SEVENTH INTERNATIONAL CONGRESS OF BRONCHOESOPHAGOLOGY

Meeting Place—Kyoto University, Kyoto, Japan

## Friday, September 12th, 1958

8 00 P M -10 00 P M —Reception (Party) Shimomura House in Kyoto

## Saturday, September 13th

8 00 A M —Inaugural Session (in Kyoto University Hall)

9 00 A M -12 00 M —First Scientific Session

12 00 M -2 00 P M —Luncheon (Reception The Place not decided)

2 00 P M -6 00 P M —Sightseeing in Kyoto

8 00 P M —Banquet, Miyako Hotel

## Sunday, September 14th

8 00 A M -11 30 A M —Second Scientific Session

11 30 A M -12 00 M —Closing Ceremony

12 00 M —Departure for sightseeing in Nara

1 00 P M —Luncheon, Nara Hotel

2 00 P M -6 00 P M —Sightseeing in Nara

7 00 P M —Return to Kyoto

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THE
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VOL LXVIII JULY, 1958 No 7

# THE MOTOR ACTIVITY OF THE CRICOPHARYNGEUS MUSCLE *†‡**

JOHN A KIRCHNER, M D ,

New Haven, Conn

Of the many muscles involved in the complex act of swallowing, none has equaled the cricopharyngeus in stimulating the curiosity of the investigator, the interest of the clinician and the respect of the esophagoscopist

First mentioned as a distinct anatomical entity by Valsalva[1] in 1717, the *cricopharyngeus* was recognized by succeeding anatomists,[2,3,4] who usually included it with the inferior constrictor muscle, as its lower-most or cricopharyngeal portion Its sphincter-like action was recognized in 1823 by Home[5] and later discussed by Mikulicz,[6] 1881, Killian,[7] 1908, and Jackson[8] in 1914 Its relation to the mouth of the esophagus was carefully studied by Elze[9] in 1929, and more recently by Leriche [10]

Its physiological identity has been further demonstrated by studies in comparative[11] and gross anatomy,[12] by roentgenographic demonstration of sphincter action,[13,14] and by the relief of post-poliomyelitic dysphagia following surgical section of the cricopharyngeus muscle [15]

Spasm of the cricopharyngeus muscle and its production by

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*Presented as Candidate's Thesis to American Laryngological Rhinological and Otological Society 1957

†From the Otolaryngology Section Department of Surgery Yale University School of Medicine

‡Aided by a grant from the George H. Knight Memorial Fund of Yale School of Medicine

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**Recipient of the Harris P Mosher Award 1958 autonomic imbalance is frequently mentioned by clinical authors as a cause of dysphagia, but without much experimental evidence to support it. One of the few basic investigations of this problem was reported by Sjoberg in 1939,[16] involving fluoroscopic studies of the barium-filled esophagus in cats after various combinations of cranial nerve sections in the neck. After bilateral vagotomy, autopsy showed a narrowed condition in both the upper and lower ends of the esophagus, attributed by Sjoberg to spastic contractions during life. Administration of ergotamine tartrate to vagotomized cats to combat sympathetic activity produced relaxation at both the cricopharyngeal and cardiac ends of the esophagus. The parasympathetic action was then simulated in these animals by injection of acetyl-choline, whereupon the cricopharyngeus relaxed and peristaltic waves were seen passing down the esophagus. Sjoberg's conclusion from these findings was that the esophageal ostia are caused to contract by the adrenergic sympathetic fibers, while the cholinergic vagus fibers bring about relaxation.

Further support for this interpretation was furnished by Rogers,[17] who reported relief of severe dysphagia in a woman with a spastic cricopharyngeus muscle on whom he performed bilateral extirpation *of the superior cervical sympathetic* ganglia. One must admire his courage as well as his surgical result, for his operation had very little experimental or clinical evidence to recommend it. Even today a sympathetic supply to the cricopharyngeus is flatly denied by Hollinshead,[18] who states that "the cricopharyngeus muscle, being a voluntary one, *is not innervated by the sympathetic system*, and there seems to be no ready explanation as to why a cervical sympathectomy should relieve spasm of this muscle, as it was reported to do by Rogers."

Although the main vagal branches to the cricopharyngeus have been identified,[19] and a sympathetic as well as a parasympathetic component is generally agreed to exist, there is no definite *mention in modern literature* as to what type of activity (contraction or relaxation) is mediated by the vagus or sympathetic branches to the cricopharyngeus.[20, 21, 22] Nor is it even certain that a specific type of activity is mediated exclusively by one or the other autonomic division as shown by studies on the cardiac end of the esophagus Carlson, for example, showed that the vagus carries both motor and inhibitory fibers to the cardia, and that the splanchnics (sympathetic) also carry both motor and inhibitory fibers to this area, the action depending on the state of contraction of the cardia at the time of stimulation [23]

The purpose of my present study, therefore, is to demonstrate, in each case, the effect of stimulation or interruption of the cervical sympathetic or parasympathetic trunks on the motor activity of the cricopharyngeus muscle

Such experimental conditions simulate the autonomic imbalance said to exist in certain cases of spastic dysphagia The resulting increase or decrease in tonus can then be demonstrated by means of a pressure-sensitive recording device placed in the hypopharynx at the cricopharyngeus level

Pharyngeal pressures during deglutition have been studied and recorded by investigators since the late Nineteenth Century In 1880 Falk and Kronecker measured the pharyngeal pressure generated during deglutition in themselves and in dogs They observed the "squirting" action on liquids and semi-solids exerted by the muscles of the mouth and the pharynx by the use of a "T" tube [24] Kronecker and Meltzer in 1883 reported their observations of the swallowing mechanism in dogs, using small balloons to record intraesophageal motility [25] Meltzer considered the squirting action to be the result of pressure exerted by the mylohyoid muscles, because he was able to eliminate it by sectioning the mylohyoid nerves He reported that this operation made the first stage of swallowing impossible, so that the bolus had to be introduced by the operator into the dog's pharynx in order for the animal to swallow [26] This same investigator, in 1907, added further evidence of the importance of the oral musculature in swallowing by cutting the middle and inferior constrictors of the pharynx in the dog, in addition to removing the muscularis of the cervical esophagus A dog, prepared in this fashion, was still able to swallow normally and could drink from a bowl of milk placed below the level of the head, thus eliminating the effect of gravity.[27] Cannon and Moser, in 1898, were the first to use fluoroscopy to study esophageal motility in animals. These workers also noted the rapid squirting action of fluids from the pharynx to the level of the heart.[28]

Although these experiments contributed much to our knowledge of the motor activity of the pharyngeal and oral musculature, the graphic recording of such motor activity was inexact, and the pressure readings unreliable.[29] It was not until 1943, with the development of an electronic device by Wetterer,[30] that a practical means of recording intraluminal pressures was made available. Wetterer described the principle of using a differential transformer to construct a miniature manometer, a system having excellent recording properties with a minimum of amplification. The device was later modified by Gauer and Gienapp[31,32] in 1950 to fit into the end of a No. 8 Cournand catheter for the recording of intracardiac and intravascular pressures. This instrument was used by Fyke and Code in 1955 for recording pressure changes in the pharyngoesophageal region during deglutition in normal human subjects.[33] Their work showed a definite pressure gradient beginning in the pharynx and traveling down through the cricopharyngeus area into the esophagus during the act of swallowing. The high pressure in the cricopharyngeus region remained unchanged throughout most of the act of swallowing, and dropped only momentarily when the pressure wave reached this area.

The activity of the individual musculature involved in swallowing was later studied by Doty and Bosma by means of electromyography. These workers took electromyographic records from 22 muscles likely to participate in deglutition. Their work substantiated that of Fyke and Code, showing a downward progressing contraction wave and an inhibition of the inferior constrictor during the entire course of lead muscle activity.[34]

## PRESENT STUDY

After controls had been established in the normal dog, the action of the cricopharyngeus muscle was studied under the following conditions:

*1* Unilateral vagus section above the ganglion nodosum

*2* Bilateral vagus section above the ganglion nodosum

*3* Faradic stimulation of the vagus and cervical sympathetic trunks

*4* Faradic stimulation of the cricopharyngeus muscle

*5* Surgical section of the cricopharyngeus muscle

The methods used in studying the motor activity of the cricopharyngeus were the following

*1* Observation of the dog's ability to swallow his usual food

*2* Endoscopic examination of the soft palate, pyriform sinuses and cricopharyngeus sphincter area with the dog under light general anesthesia

*3* Fluoroscopic and roentgenographic studies of the hypopharynx with barium mixtures

*4* Pressure changes in the hypopharynx at the cricopharyngeus level during deglutition, using an electronic pressure-sensitive pick-up

These methods are standard and seem self-explanatory except for the last, which requires further explanation

In the beginning of this experiment we were using a Gauer-type pressure capsule attached to the proximal end of a 2 mm polyethylene tube introduced through the mouth to the cricopharyngeus level, and recording the motor activity of the cricopharyngeus by means of a Hathaway oscillograph This gave satisfactory and sensitive responses, as shown by Fyke and Code, but seemed to have certain disadvantages First, if a fold of mucosa came to overlie the end opening (or side opening as was later tried) the pressure determination was interfered with, therefore, the open end was enclosed in a small, partially inflated balloon This, however, was soon abandoned because of distortions produced in the balloon by the contracting cricopharyngeus muscle, with resultant inaccuracies in the reproduction of intraluminal pressures

My chief objection, however, to present techniques of recording pressures at the cricopharyngeus level is that this area is pulled upward during swallowing, so that a recording device introduced to the level of the cricopharyngeus sphincter at rest and kept at this level during swallowing is recording pressure not in the cricopharyngeus segment but in the upper cervical esophagus While there is some evidence that a small polyethylene tube will ride up and down with the cricopharyngeus[35] during deglutition, there seemed enough doubt on this point to have warranted the construction of a pressure-recording device which would respond with equal sensitivity along a 3 or 4 cm distance If such a device were of small diameter and of smooth surface it could be introduced into the pharyngo-esophageal junction behind the cricoid cartilage, allowing the cricoid and cricopharyngeus to ride up and down over it, and recording the motor activity of the cricopharyngeus whether it was elevated or at rest

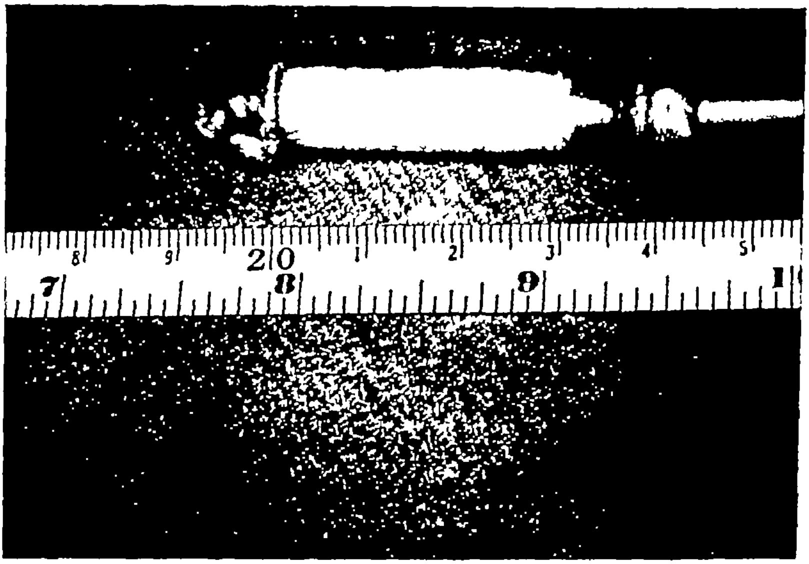

Fig 1 Pressure-sensitive electronic pick-up used in hypopharynx at cricopharyngeus level

For the development of such a recording device I am indebted to Dr Albert Field, Jr , of the Cardiopulmonary section of the Department of Internal Medicine A pressure-sensitive

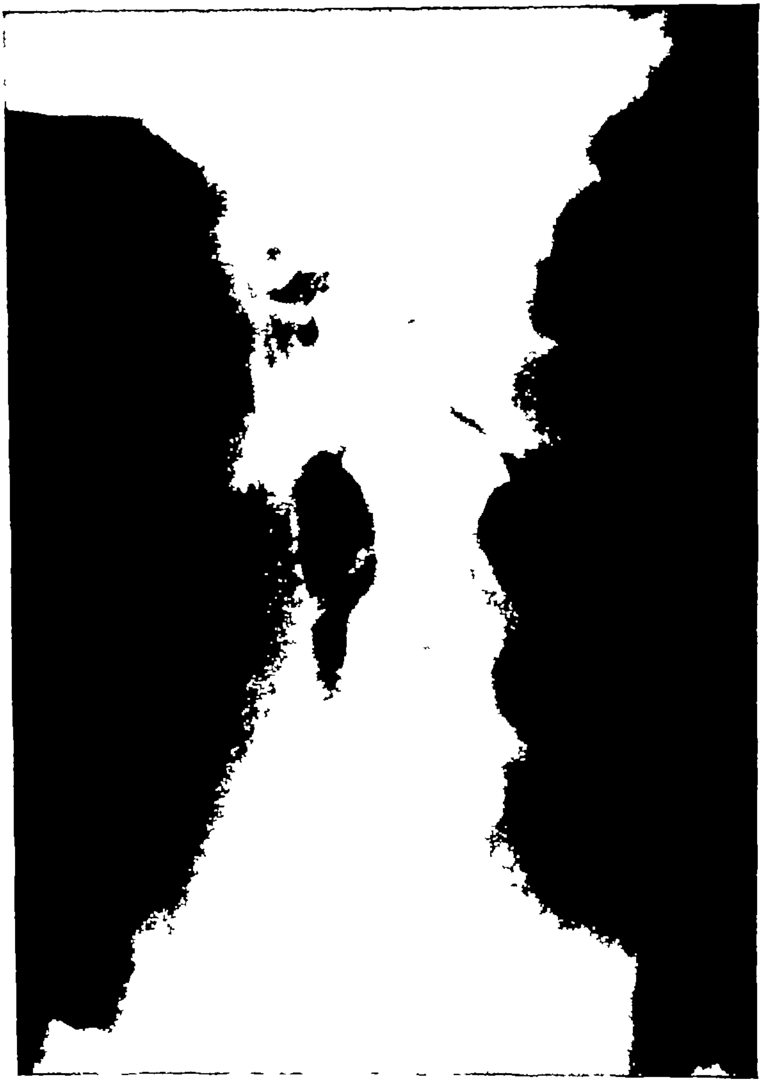

Fig 2 Dog No 1—Normal AP view after barium swallow The trachea deviates to right in supine position in this case but may deviate to left, as seen in other examinations

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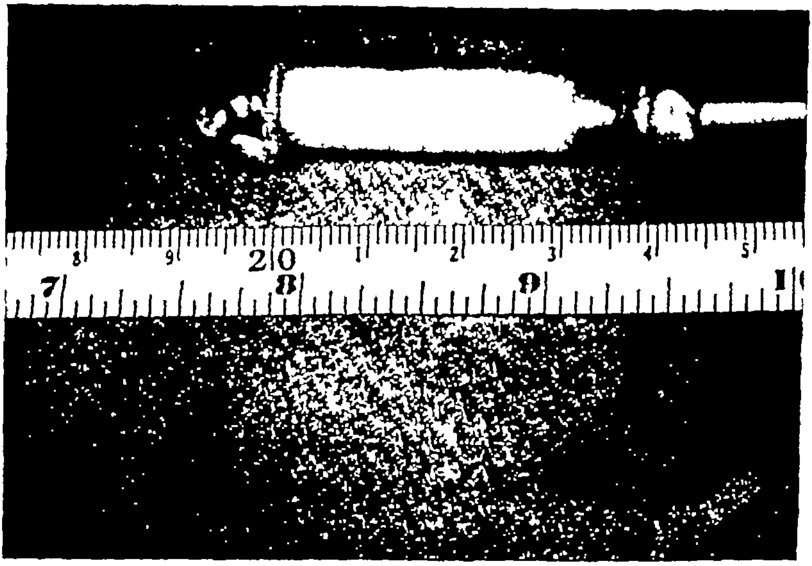

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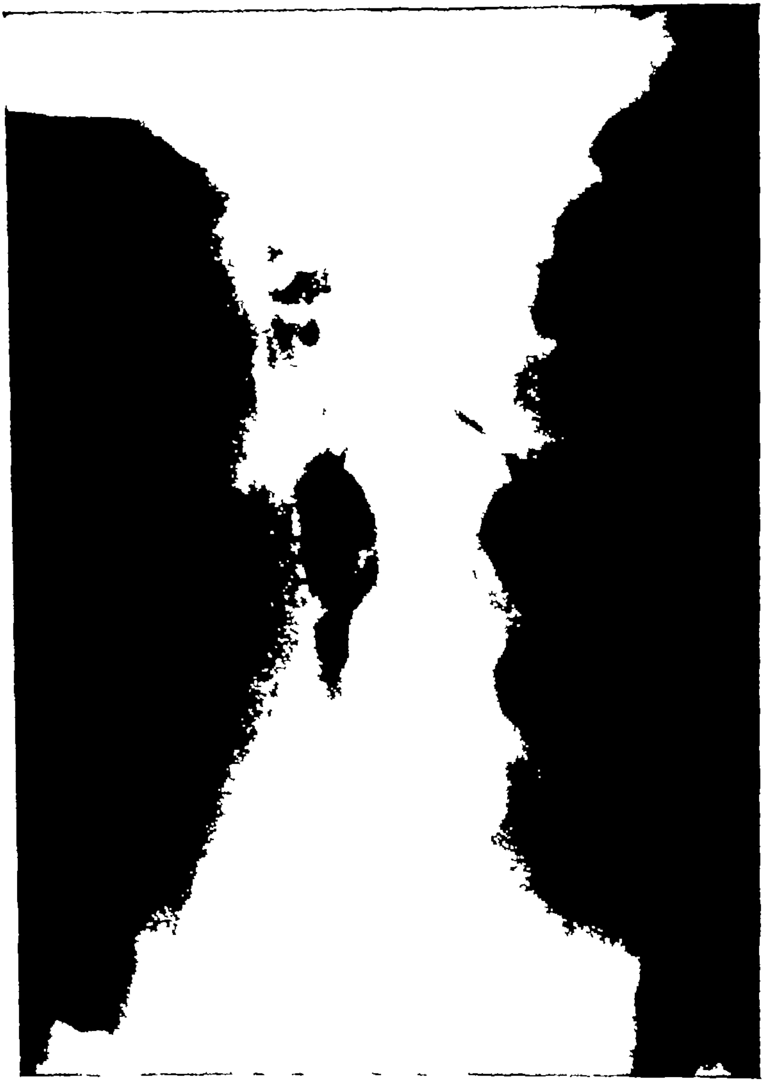

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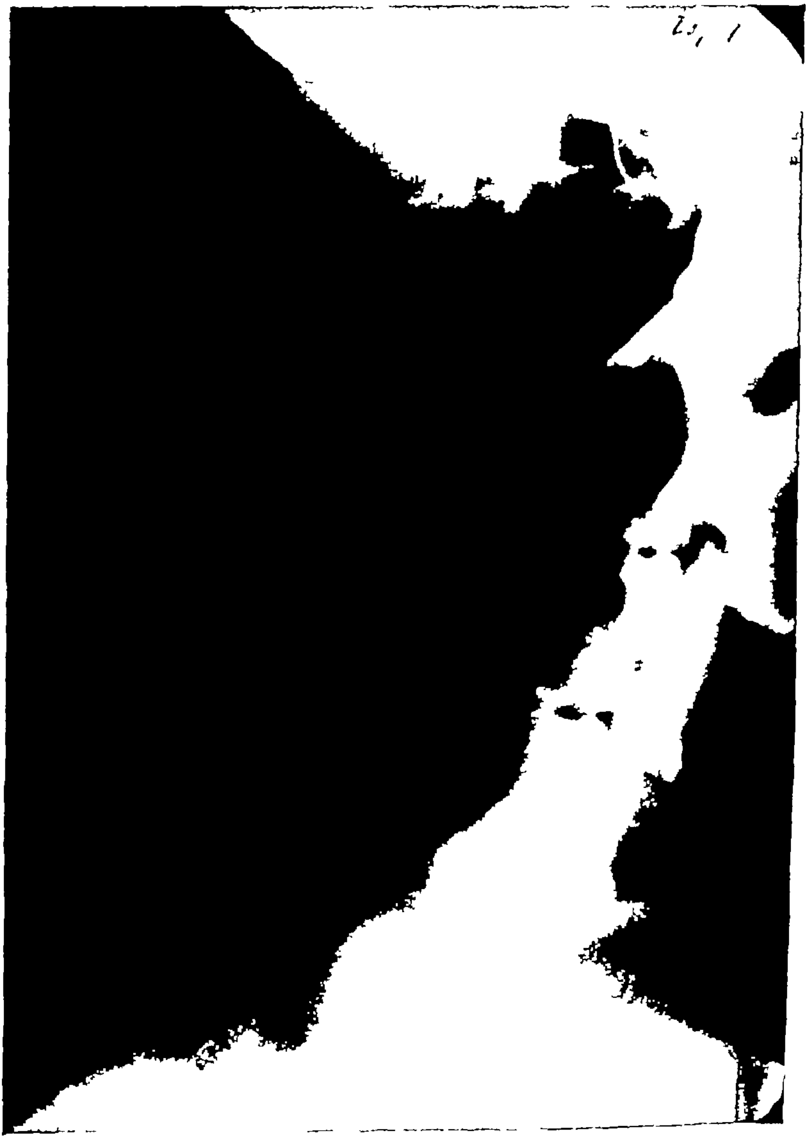


Fig 3 Dog No 1—Normal lateral view after barium swallow A very small amount of barium remains in the valleculae

pick-up was constructed, consisting of a variable capacitance which measures pressure changes by means of variations in a tuned circuit, based on a principle described by Buchtal and Warburg in 1943[3c] It is equally sensitive to pressure at any point along the distance of 3 5 cm, and allows a permanent record to be made by a direct writing electrocardiographic instrument

The equipment has been checked for performance against a Sanborn pressure capsule and found to be accurate, sensitive and brisk in response Calibrations and other details are described in a separate report

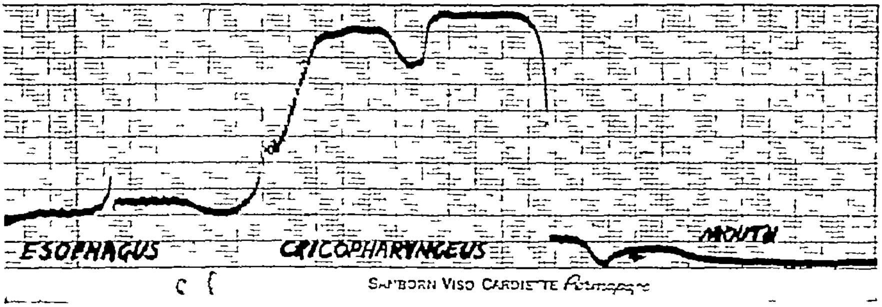


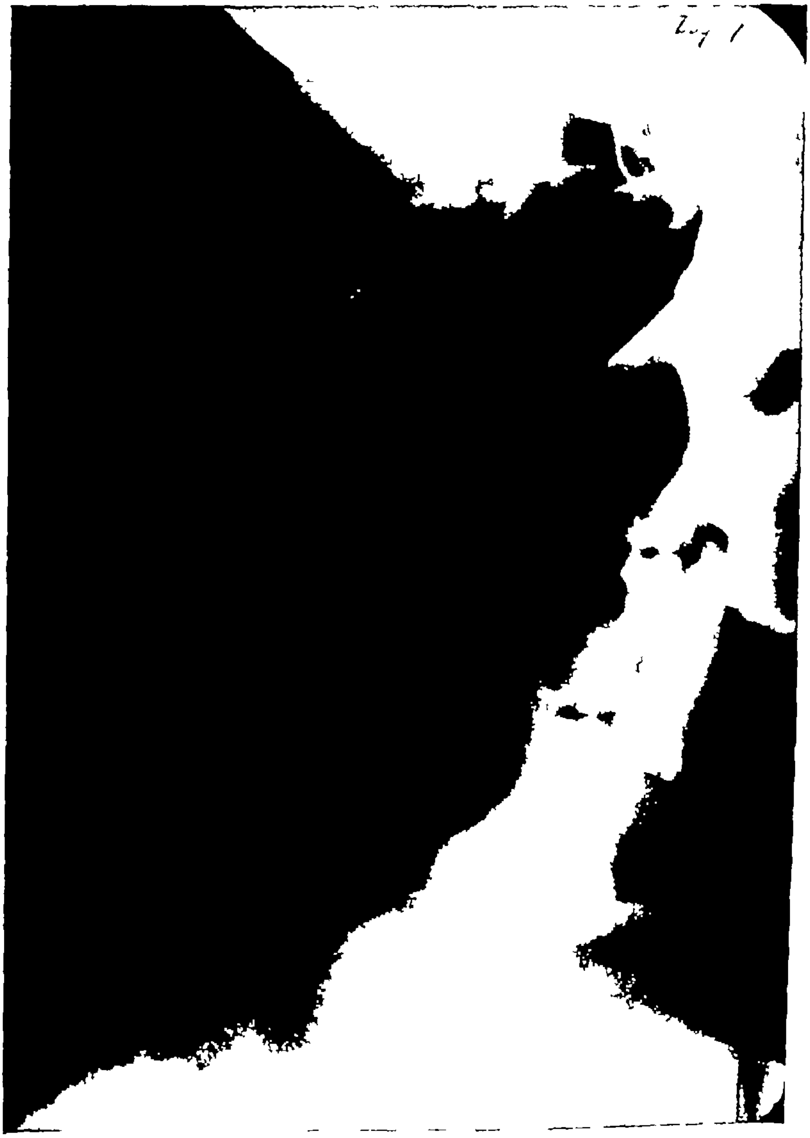
Fig 4 High-pressure area encountered at cricopharyngeus as cable is withdrawn from thoracic esophagus

Because of variations in the base line under different operating conditions, calibrations for exact pressures are not reliable The calibrations are included, nevertheless, (mm Hg) to indicate direction of deflections with positive and negative pressure and to indicate approximate pressure ranges Changes in pressure are, of course, readily demonstrated by the shape of the curves

## NORMAL DOG

*Deglutition* Ate regular diet without difficulty

*Endoscopic Examination* The soft palate, pharynx, larynx and tongue move normally A definite annular contraction was seen behind the cricoid cartilage



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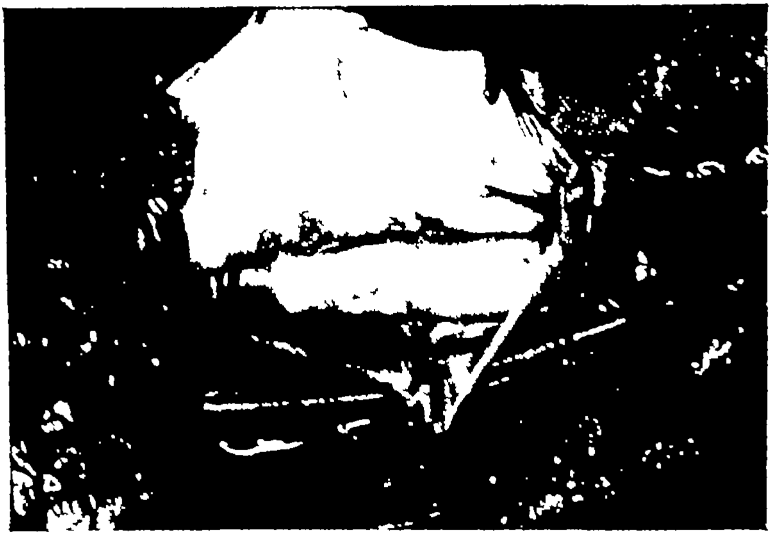

Fig. 6. Dissected specimen showing pressure pick-up in position at cricopharyngeus level.

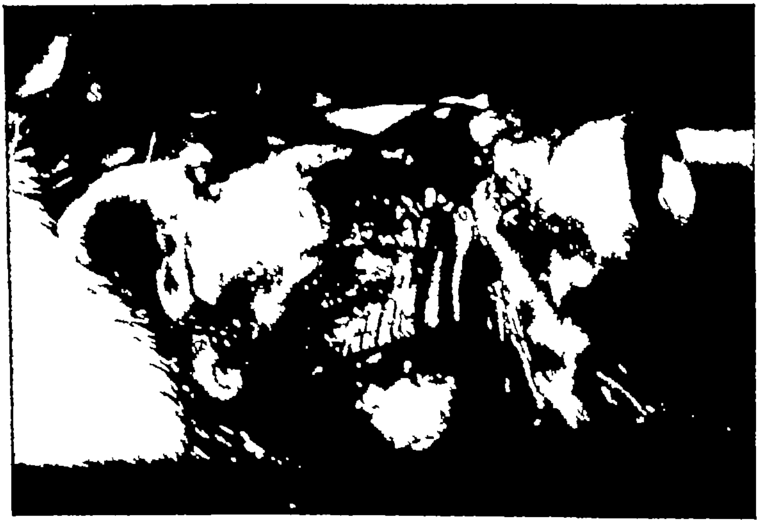

Fig. 7. Dissected specimen showing cricopharyngeus and thyropharyngeus portions of inferior constrictor muscles. (Operator's finger is in lumen of hypopharynx.)

*X-ray* Fluoroscopy of a thin barium mixture showed rapid descent of the liquid from the mouth to the level of the heart with no tendency to collect in any of the pharyngeal recesses A normal soft tissue pattern behind the cricoid cartilage was seen on the lateral views (see Figs 2, 3)

*Pressure Studies* Because of the fact that deep general anesthesia abolishes the swallowing reflex, light nembutal anesthesia was used Pressure readings were made when the deglutition reflex could be stimulated by gently stroking the posterior pharyngeal wall

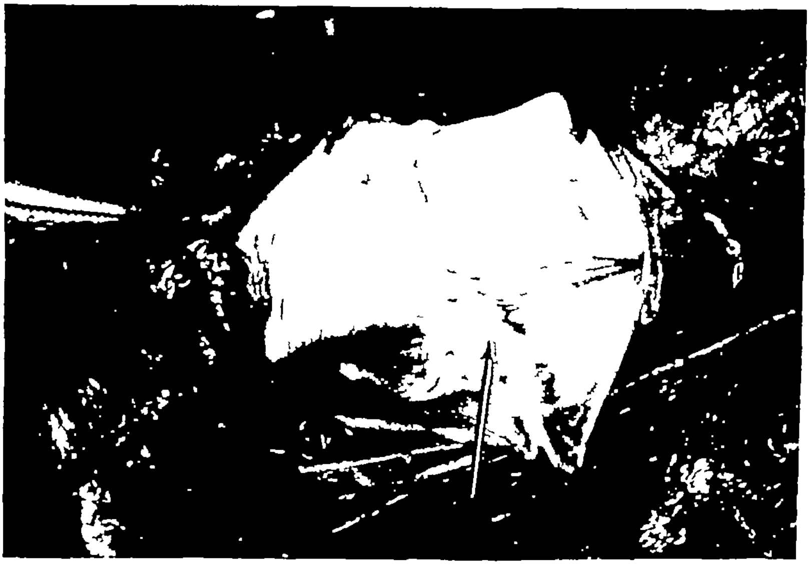

Fig 5 Dissected specimen showing annular fold in hypopharynx behind cricoid cartilage

The pressure capsule was first introduced into the thoracic portion of the esophagus and the recording base line adjusted on the recorder The capsule was then slowly pulled up from the esophagus into the mouth, during which an area of high pressure was encountered in the cricopharyngeal region (see Fig 4) This was a constant finding, whether the dog was in a prone or supine position This high pressure area was found to be 19 5 cm from the upper incisor teeth and corre-

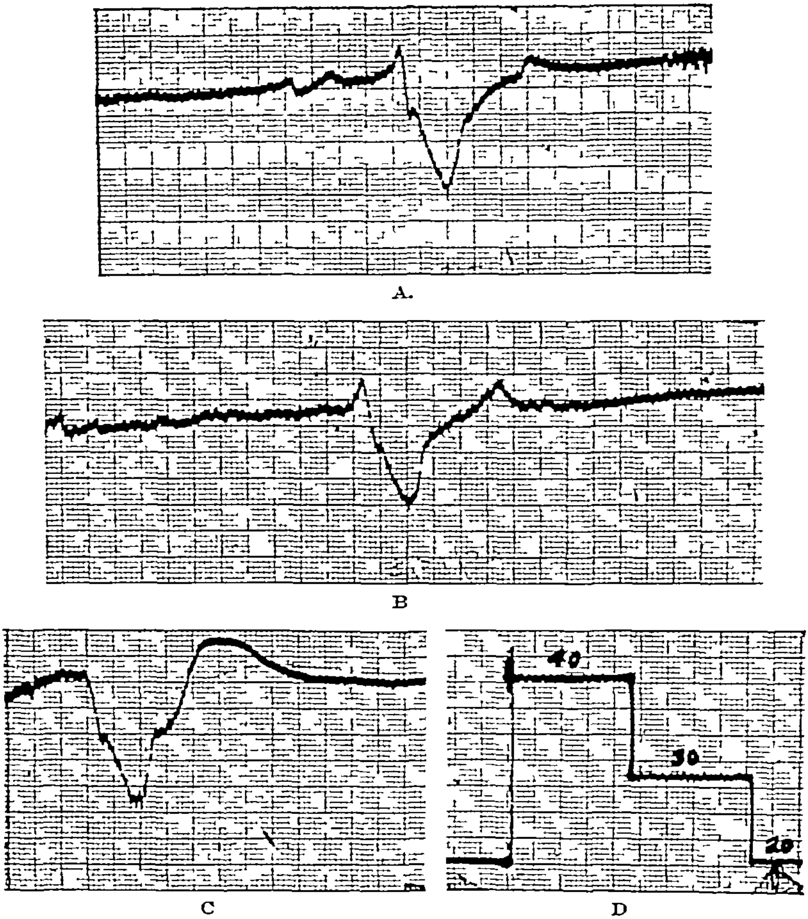

Fig 9 A.-B-C—Pressure recordings from cricopharyngeus level during act of swallowing D—Calibration (mm Hg)

nodosum, where it joins the superior cervical sympathetic ganglion The pharyngeal ramus of the vagus, which supplies parasympathetic innervation to the constrictor muscles leaves the vagus trunk cephalic to the ganglion nodosum at its point of emergence from the jugular foramen Whether the sympathetic trunk gives off separate rami to the pharyngeal plexus or to the pharyngeal musculature along its cervical course, as it does in man, I could not determine from the available literature (see Fig 10 for details) sponded almost exactly to the area of annular constriction seen on endoscopic examination (see Fig 5) The mid-point of the recording capsule was introduced to this level for deglutition patterns and other studies in this dog (see Fig 6)

The swallowing patterns shown here illustrate the characteristic curve obtained in all our experimental animals At the beginning of cricopharyngeal activity a small rise in pressure can be seen, probably corresponding to the advancing peristaltic wave Almost immediately the cricopharyngeus undergoes a marked relaxation, followed again by a contraction, which may rise to or above the original base line level (see Fig 9)

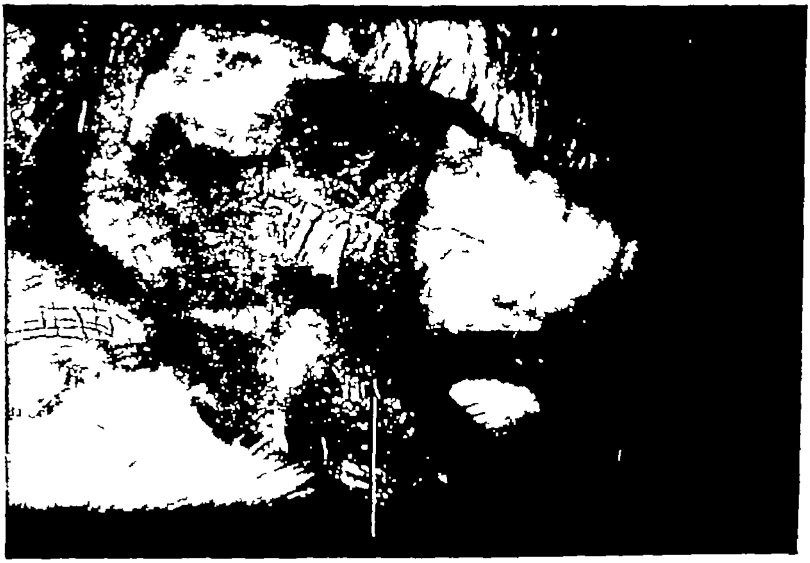

Fig 8 Dissected specimen showing cricopharyngeus portion (arrow) of inferior constrictor separated from thyropharyngeus Pressure determinations were made at cricopharyngeus level

## SECTION OF ONE VAGUS NERVE

In the dog the vagus nerve carries with it the sympathetic trunk throughout most of its cervical course The sympathetic joins the vagus opposite the inferior cervical sympathetic ganglion and leaves it again just caudal to the ganglion

*X-ray* The barium mixture cleared the pharynx easily There was no residual barium in any of the pharyngeal recesses nor were there any changes in the soft tissue patterns (see Figs 12, 13)

*Pressure Studies* Swallowing patterns show much less relaxation of the cricopharyngeus during swallowing, with a higher positive pressure (see Figs 14, 15)

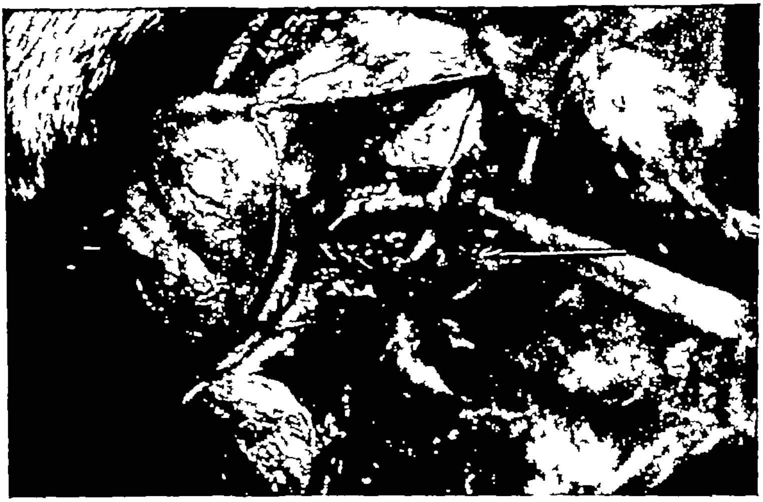

Fig 11 Vagus nerve (arrow) approaching base of skull

## DISCUSSION

It is interesting that this dog had no dysphagia, although there was a curtain movement of the pharynx, deviation of the soft palate, and paralysis of the right vocal cord This may be due to the fact that the free portion of the epiglottis of the dog lies above the soft palate, allowing the ingested food and liquids to pass down lateral to the larynx and affording added protection to the laryngeal inlet during the act of swallowing The decreased relaxation of the cricopharyngeus during deglutition following unilateral vagus section may be due to an over-activity of the remaining sympathetic nerve supply I do not believe it is due to a lower starting pressure,